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Capital services, labour productivity and economic growth in Finland, 1996-2015

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Taloustieteessä vallitsevan käsityksen mukaan pitkällä aikavälillä talouskasvu ja elintason kohoaminen ovat riippuvaisia työn tuottavuuden kehityksestä. Monissa OECD maissa työn tuottavuuden kasvu oli hidastunut jo ennen vuoden 2008 talouskriisiä. Suomen talouskasvu ja työn tuottavuuden kasvu on miltei pysähtynyt 2000-luvulla. Tietointensiivisen pääoman karttumisen hidastuminen voi olla yhtenä selittävänä tekijänä kyseisen ilmiön takana. Tämän pro gradu –tutkielman tarkoituksena on tutkia Suomen tuottavuuskehitystä ja löytää selittäviä tekijöitä 2000-luvun supistuneelle kasvulle. Tutkimus perustuu kasvulaskennan malliin, jota on laajalti käytetty OECD ja Euroopan maiden tuottavuuskehitysten tarkasteluissa (esim. EUKLEMS-projekti). Kasvulaskennan puitteista tämä tutkimus keskittyy erityisesti kokonaistuottavuuden, ICT- ja T&K-pääoman vaikutuksiin talouskasvuun sekä työn tuottavuuteen. Tutkielman tulokset osoittavat, että talouskasvun ja työn tuottavuuden hidastuminen johtuvat suurimmaksi osaksi kokonaistuottavuuden voimakkaasta supistumisesta. Aiemmin T&K-pääomalla oli myös suuri positiivinen vaikutus talouskehitykseen sekä työn tuottavuuden kasvuun. Viime vuosina T&K-pääoman vaikutus on romahtanut, mikä heikensi talouskasvua ja työn tuottavuutta entisestään. ICT-pääoman vaikutus talouskasvuun 2000-luvun puolivälin jälkeen on myös heikentynyt mutta tämän pääomalajin kontribuutio talouskasvuun ja tuottavuuteen säilyi positiivisena. Kokonaistuottavuuden epäsuotuisa kehitys koko kansantalouden tasolla viittaa tuotantoresurssien tehottomaan käyttöön sekä siihen, että Suomessa ei ole tarpeeksi innovaatiotoimintaa, joka tehostaisi tuotantoprosesseja ja loisi tuotannolle lisäarvoa. Korkean teknologian teollisuustoimialat ovat aiemmin olleet merkittävässä asemassa työn tuottavuuden sekä talouskasvun synnyttämisessä. Kyseisten toimialojen negatiivinen kehitys 2000-luvun puolivälin jälkeen on tärkeä syy talouskasvun hidastumiselle ja tuottavuuden pysähtymiselle. Korkean teknologian teollisuustoimialojen vaikutus kokonaistuottavuuteen, työn tuottavuuteen ja talouskasvuun on romahtanut.

Avainsanat kokonaistuottavuus, MFP, työn tuottavuus, pääomapanoksen disaggregointi, ICT -pääoma, T&K-pääoma, pääomaintensiteetti

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Abstract

In the long run, labour productivity is the motor of improvements in the standards of living and economic well-being. In many OECD countries, productivity growth had slowed even before the financial crisis in 2008. In Finland, economic growth and the development of labour productivity have been regressive in the 21st century. The slowdown in knowledge-based capital accumulation could be one of the possible reasons for the stagnation. This study decomposes the capital input and takes a closer look at the reasons behind this phenomenon. The contributions of the components of total capital input provide detailed information about the development of labour productivity and economic growth. Since we are currently living the past ICT-boom period and it seems that new technology breakthroughs are getting harder and harder to find, special attention is given to the sets of ICT and R&D capital. This study is based on the growth accounting framework firstly acknowledged by Solow (1958) and further improved by Jorgenson. The methodology follows closely the steps of EUKLEMS and OECD productivity projects. The results of this study imply that the great cause of productivity stagnation is assigned to the negative development of multifactor-productivity and a significant decline in the contribution of R&D capital. The contribution of ICT capital has declined in the past decade but it has still remained highly positive. The negative development of MFP at the whole economy level indicates a loss of innovative abilities and an inefficient usage of the resources. The diminished contributions of the high-tech manufacturing industries to the development of MFP, value added and labour productivity are a major reason behind the detected stagnation. The results imply that previously highly productive manufacturing industries have lost their productive efficiencies.

Keywords multifactor-productivity, MFP, labour productivity, capital input disaggregation, ICT capital, R&D capital, capital intensity

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1. Introduction

It is widely agreed upon by economists that in the long run increases in labour productivity are the key determinants of living standards. Paul Krugman noted in 1994: "Productivity isn't everything, but in the long run it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker. Productivity is about "working smarter", rather than "working harder" (The Future of productivity OECD 2015). It reflects the ability to produce more output by better combining inputs, more efficient usage of resources, creating new ideas, technological innovations and business models. Because of its far-reaching effects that cover the development of whole economy, raising productivity is a fundamental challenge for countries going forward. History has seen productivity leaps with innovations such as the steam engine, electrification and breakthrough of ".com" and ICT equipment.

Following the 2008 financial crisis, Finland has been struggling with returning back onto a path of a steady economic and labour productivity growth. The average annual growth rate of labour productivity in the period of Nokia and the ICT-boom (1996-2005) was 3.05 percent. In the following period of 2006-2015, the growth had collapsed to only 0.15 percent[1] per year. The average annual development of economic growth in terms of value added in corresponding periods was 4.76 and 0.14 percent, respectively. This situation creates an impression that this glorious high-tech economy with, "the best free education in the world" and one of the highest living standards is losing its grip and is at risk to become a "fallout". The productivity literature has disclosed its concern on declining accumulation of ICT and especially R&D capital. This concern is reasonable since at the beginning of 21st century these sets of capital have had a major role in creating value and improving labour productivity and thus, living standards. Contribution of these capital sets is a highly interesting matter to investigate with fresh Finnish data.

The main objective of this study is to deepen understanding of the reasons behind stagnation of economic growth and labour productivity. This is done in respect of three main factors – ICT and R&D capital and multifactor-productivity. Consensus exists that behind labour productivity and economic growth stands the growth of multifactor-productivity (MFP). The great contribution of this study to the productivity researches concerning Finland is disaggregating the capital input. In other words, the detailed analysis of development of labour productivity and economic growth is executed

[1] Values are measured in logarithmic terms (average annual logarithmic percentage changes).

by retrieving the separated contributions of each individual asset type. All in all, four different asset groups are formed. The earlier productivity related literature has paid a lot attention to as flawless as possible measurement of capital (Jorgenson and Griliches 1967; Jorgenson et al 2005). After commercialization of interned in 1995 and following boost of “wireless” economy, the literature in productivity studies has long emphasized the importance of investment in information and communication technology (ICT) for accelerating economic growth and labour productivity (e.g. Griliches 1991). The interest towards the contribution of R&D capital to economic development has awoken in recent studies (e.g. Bloom, Van Reenen, Jones and Webb 2017; Goodridge, Haskel and Wallis 2015). This analysis of changes in labour productivity and economic growth with the focus on detailed contributions of different capital groups is one of the few performed for aggregated Finnish economy. One of the advantages of this exercise is the usage of the latest data available.

The first chapter consists of introduction and presents the results of previous studies. Second chapter exhibits the methodology. A detailed construction of each variable is presented. Chapter 3 discusses the sources of data used in the research. Chapters 4 and 5 present the results of this study. The fourth chapter discusses the development of economic growth and labour productivity. As well, the contributions of relevant components are analyzed in Chapter 4. Chapter 5 inspects the structural changes in the economy. Chapter 6 contains the discussion of the results and chapter 7 concludes and summarizes the study.

1.1 Surveys of related studies

This section shortly presents the results of previous national and international studies that have studied this topic. The interest towards the role of capital in total and various capital assets in value creation and initiating economic growth dates long back before Solow incorporated the modern concept of growth accounting framework in 1958 (see Griliches 1995). The resurgence of American economy since 1995 brought a new wave of interest towards capital. Although, even before that the different productivity characteristics of distinct asset types have been recognized (e.g. Jorgenson and Griliches 1966; Jorgenson and Griliches 1967), at the beginning of the 21st century the focus of productivity studies shifted towards highly productive ICT capital. In following paragraphs the main results of relating surveys are presented. The literature on productivity research is vast. The studies presented here are inspected strictly from the point of view of capital services and multifactor-productivity.

Since the EUKLEMS – project started in 2003, there have been many studies on multifactor- and labour productivity in European Union. The EUKLEMS-project aimed at building an international productivity database for analyzing productive characteristics of European Union as well as few selected OECD-countries from the year 1970 onwards. The study by van Ark, O´Mahony and Timmer (2008) uses the EUKLMES dataset to analyze the differences in growth rates of labour productivity in EU15 and U.S. Finland is included to this study.

Van Ark *et al.* (2008) use the same methodological approach adapted in this study. The specific attention is given to contribution of ICT capital. The study compares the productivity performance of two economic areas in several periods of time: before 1950´s, from 1973 to 1995, when the growth of both areas slowed down, and the last period covers the timeline after the 1995. Van Ark *et al.* (2008) find that the productivity growth in U.S is attributed to rapid development of productivity in market services in the early 2000s and to high investment levels in highly productive information and communication technology in the mid 90´s. The slower development of Europe is explained by significantly slower multifactor-productivity growth and lower contribution of ICT capital, which can be partly linked to relatively smaller share of technology-producing industries than in U.S. They conclude that the model of 1950´s, where Europe could catch-up by imitating the new technologies, is not sufficient anymore. This is because the knowledge-intensive services are harder to imitate. The long-awaited productivity growth requires a new model of innovation and such development activity that makes better use of a country´s own innovative capabilities (van Ark, O´Mahony and Timmer 2008).

Since the mid 2000´s there haven´t been many macroeconomic studies for Finland analyzing the contribution of ICT capital (or contributions of other capital assets) in growth accounting framework. However, there are two studies worth mentioning since they are of a high importance to productivity surveys in Finland and the results of these studies are highly interesting.

The first study that is introduced was conducted by Pohjola and Jalava (2008). They study the differences in contributions to economic growth of two advanced technologies of own times: the electricity and ICT capital. The method used to achieve estimates is more advanced and sophisticated that the one used in this thesis. The authors compute a model based on pure growth accounting model in term of value added but also add an additional regression to standard growth accounting model. Jalava and Pohjola (2008) explain that in basic model there are two channels through which the new technology can generate the growth in value added (output). These two ways are the improvement of multifactor-productivity and capital deepening resulting from new capital such ICT or R&D capital. An additional regression helps to identify the multifactor-productivity spillovers from technology-producing sectors to sectors, which implement and start using the new technology (but do not produce it themselves). The comparison was done with the U.S estimates.

The main results of this study (Pohjola and Jalava 2008) can be summed up as the ICT capital had contributed more than electricity to Finnish economic growth, and the ICT´s contribution has been larger in Finland than in the United States. The contribution of pure ICT capital to economic growth in Finland was close to 0.2 %-points in both inspection periods. The multifactor-productivity played an important role with contribution of 1.48 %-points in 1980-1990 and 2.51 %-points in 1990-2004.

The second study was performed by Pohjola (2011). This study is highly important, because it created foundation of modern productivity research in Finland. In cooperation with this article, the Finnish productivity database was created and the growth accounting method was incorporated in productivity surveys of Statistics Finland[2]. The development of productivity database and the study by Pohjola (2011) were also linked EUKLEMS-project.

For result considering Finland the research by Pohjola (2011) uses the same data sources as are used in this thesis. The methodologies applied are also the same. The timeline of research by Pohjola (2011) is 1980-2008. Although, the timeline don´t match, the study gives rather comparable estimates for this thesis.

This study (Pohjola 2011) reveals that the labour productivity growth had suppressed from an average of almost 3 % growth in period of 1990-2000 to 1.8 % in the early 21st century. The decelerating growth can be explained by that the growth of labour productivity in all industries has been slower. In addition, Pohjola (2011) finds that working hours have been allocated towards industries with lower productivities.

The main determinants of growth had been the multifactor-productivity and capital. The multifactor-productivity accounted for 2/3 (almost 2 %-points) of total labour productivity growth in the 1990s. The effect of multifactor-productivity declined to approximately 1.3 %-points at the beginning of 21st century, which, however, is still a considerably high level. In comparison of earlier period of 1980s the contribution of capital intensity (capital per hour worked) was considerably higher than in the 2000s. In period from 2000 to 2008 capital contributed to growth in labour productivity by 0.5 %-points. Before that the contribution reached almost 1%-point level. (Pohjola 2011)

Pohjola (2011) analyzes the structural changes that have occurred in the Finnish economy. The result suggest that the most important industries for economic growth had been four big manufacturing

[2] This methods is still in use in Productivity Surveys of Statistics Finland.

industries: the forest industry, the industry of electrical engineering, manufacturing of machines and metals and the information and communication services. In the period 2000-2008 economic growth and favourable labour productivity development is due to growth in industries of electrical engineering and ICT services.

2. Industry level productivity measurement in the growth accounting framework

This chapter provides a closer look into the methodology used in this thesis. The methodology chapter combines the measurement of output (in terms of value added) and productivity growth both in theory and practice. The method is based on growth accounting and follows closely the implementation methods advised by Jorgenson, Stiroh and Ho (2005), EUKLEMS - project and OECD productivity manual. The modern approach to measuring productivity in growth accounting framework has been in many respects motivated and put into a more general framework by Jorgenson *et al.* (1987)[3] (O'Mahony and Timmer 2009). The OECD productivity projects and the EUKLEMS project rely strongly on methods developed by Jorgenson in his seminal work.

The productivity analysis is based on the neoclassical production function theory. In general, there are two parallel ways of measuring output and productivity measures: one based on aggregate gross output and the other that is based on value added terms. The choice of this thesis is the one based on value added. This method is entrenched in the literature and provides some features which suite better for whole economy analysis. There are differences in the assumptions behind these two methods but the main contrast is that aggregated output method takes note of intermediate input, whereas the value added method focuses on just primary inputs. The exclusion of intermediate input occurs due to the definition of value added. Value added is the difference between gross output and intermediate inputs. Value added follows closely the GDP but is not, however, exactly the same measure. By adding the product taxes and deducting the payed subsidies the measure of GDP is achieved.

The divergence of these methods exists only on industry level analysis. According to Jorgenson *et al.* (2005), the final result on aggregated level for the whole economy is eventually the same. This study does not comment on the differences of these methods[4] and focuses strictly on the mainstream method used internationally in productivity studies –the value added method.

[3] Earlier contribution of Jorgenson and Griliches (1967) had a seminal contribution to development of measurement of productivity in growth accounting framework, but Jorgenson *et al.* generalized the approach.
[4] For additional discussion regarding gross output and value added methods of calculating productivity see the Annex.

In economy value is generated by inputs. The primary inputs are labour and capital. The neoclassical production theory assumes that in addition to primary inputs, there is one influential factor that affects the production in a great manner − technology and innovative improvements. In this form, the production function for industry j is presented by equation (1). This model was firstly pioneered by Robert Solow in 1958.

(1) $Y_{j=}f_j(K_j, L_{j,}, T)$

The output in each industry is a function of capital (K_j), labour (L_j) and technology (f_j). T is the time index. Each industry, j, produces a set of output products with certain value (Y_j) using the number of inputs it bought. All the inputs of equation (1) are measured as indices of service flows.

In this study, the methodology is based on value added production function. From now on, the term output is used as a synonym for value added and must not be disarrayed with the gross output that was mentioned in the previous paragraph. The approach used in this thesis is "bottom-up", that is to say that firstly each component is calculated for each industry and then the measures are aggregated to the level of whole economy from base industry level. This type of aggregation is called direct aggregation across industries.

To apply the value added method, some additional assumption must be made: the value added method requires that production function is separable in capital, labour and technology. Further, under familiar assumptions of constant returns to scale, full input utilization levels and perfectly competitive markets, the total growth of value added can be expressed through cost-share weighted growth rates of each input and technological change. (O'Mahony and Timmer 2009) Using a translog function, which is a more general form of Cobb-Douglas production function, the change of output growth can be expressed as follows:

(2) $\Delta lnVA_{j,t} = \bar{v}_{L,j,t}\Delta lnL_{j,t} + \bar{v}_{K,j,t}\Delta lnK_{j,t} + \Delta \ln MFP_{j,t}^{VA}$

- Where $\Delta lnMFP_{j,t}$ represents the technological change at industry j at time t.
- $\bar{v}_{i,j,t}$ are the cost-share weights of each input, respectively, combined as two year average shares.
- All the weight must sum up to 1 as follows: $\bar{v}_{K,j,t} + \bar{v}_{L,j,t} = 1$. This restriction applies also, when capital input ($\Delta lnK_{j,t}$) and ($\Delta lnL_{j,t}$) are decomposed to subcomponents e.g. $\Delta lnK_{j,t}{}^{ICT}$ (contribution from ICT capital to value added) and $\Delta lnK_{j,t}{}^{non-ICT}$(contribution from other capital services to value added).
- The primary inputs of equation (2) are measured as Törnqvist indices of service flows.

The equation (2) is baseline for productivity calculations. Despite it is firstly presented in this section, it will be referred to in industry level calculations of capital services and multifactor-productivity. The time index t can be suppressed from the equation.

The equation shows how much each component has contributed to the annual growth of value added. In other words, the annual change in value added is decomposed in weighted contributions of capital and labour services and – the technological or production method improvements – the multifactor productivity (MFP). Hence, the change in value added is dependable on changes in these three factors.

The greatest contribution of this study is that the further decomposition of capital input is done. This matter is discussed more specifically in section 2.2.4 but is an important matter to mention right from the start, since this study uses the latest dataset available and decomposes the contribution of total capital in growth accounting framework. Analogous analyses have been made earlier but not with the latest data, which is also now available for a broader audience. For previous studies see for example Pohjola (2011), Jalava and Pohjola (2008) and Aulin-Ahmavaara, Jalava (2003).

The contributions of each asset type group (e.g. contribution from ICT capital to value added ($\Delta lnK_{j,t}{}^{ICT}$)) are extracted for each industry. The correct measurement of inputs provides a possibility to distinguish the substitution between heterogeneous components. As an example, the value added growth can be generated through growth of capital input. The changes in growth of capital input occur due to increased investment activity or due to experienced substitution from long-living assets towards short-living assets. Such assets as computers and other ICT equipment have a relatively short life cycle but high productivity. (Jorgenson *et al.* 2005) This study captures the essential differences between heterogeneous contribution rates of each asset type group.

Following subsections present the formation of all inputs that are needed for determination of economic growth in terms of growth accounting model based on value added. The main focus of this study is on capital input.

2.1 Labour input

When measuring labor input, the standard measures of labour input use such indicators as number of employed or hours worked. However, in productivity analysis various types of labour – e.g. low skilled versus high-skilled or age group 15-29 and 30-54 –differ in their marginal productivities. If one simply summed up the hours worked to represent the total labour input, it would not account for differences in marginal productivities of different labour types such as high-educated 30-54 years old employees versus employees, who have lower education level and belong to the age group 15-29.

This would be the case if one would use the standard measures of labour input. Thus, in productivity analysis, the labour input measure captures the changes and the contribution of hours worked as well as the changes that occur in labour composition and its contribution to labour productivity and value added. (Jorgenson *et al.* 2008)

The measure used in this thesis follows the methodology presented in the EU KLEMS projects (Timmer, O´Mahony and van Ark 2007). There is a large consensus in the literature that different labour types have individual influence on value added and labour productivity. Such a measure of labour input must be computed that accounts for the heterogeneity of the labour force. Rather than measuring the labour input as the total amount of hours worked or numbers of employed, the productivity analysis focuses on labour services (OECD: Measuring Productivity manual 2009). The key assumption is that the flow of labour services for each labour type is proportional to hours worked, and that workers are paid for their marginal productivities. This leads to the conclusion that the wage of each labour type group represents its marginal productivity. The measure of labour services correctly accounts for differences in the amounts of services delivered per unit of labour. An important outcome emerges from this method: the method based on labour services captures the magnitude of diverge contributions of each labour type to value added or labour productivity.

Firstly, the industry by hours worked are cross-classified into labour type groups accordingly. After the hours worked have been assigned to proper categories, the annual logarithmic change are calculated. The annual change rates represent the changes in hours worked in each compensation group (e.g. in schooling, age or gender). When assumed that the average income level of each compensation group represents marginal productivity of this group, the labour services input for a particular industry can be calculated as follows:

(3) $\Delta lnL_j = \sum_l(\bar{w}_{L,lj}\Delta lnH_{l,j})$

- Where $\Delta lnH_{l,j}$ is the growth of hours worked by labour type *l*
- $\bar{w}_{L,lj}$ is the weight, which consists of average wage for labor type *l* of two sequential years
- $\bar{w}_{L,lj} = 0.5 * (w_{l,j,t} + w_{l,j,(t-1)})$

The industry specific labor input is expressed in form of Törnqvist volume index and consists of the change in hours worked of each compensation group ($\Delta lnH_{l,j}$) and the average wage weights ($\bar{w}_{L,lj}$) for individual labour types (*l*). Recalling the earlier statement, where the wage of each labour type ($w_{l,j,t}$) represents the marginal productivity of that particular labour group; the variable ($\bar{w}_{L,lj}$) indicates the average wages and thus the productivity for each labour type group. When the weighting is done for each group, the ultimate result is summed up to be one aggregate labour input$-\left(\Delta lnL_j\right)-$ for the exact industry *j*.

The weighting is important because it reflects different productivities. When assuming that marginal revenues are equal to marginal costs, the weighting procedure ensures that inputs, which have a higher price also have a larger influence. This means that, for example, a doubling of hours worked by a high-skilled worker gets a bigger weight than a doubling of hours worked by a low-skilled worker (Timmer and O´Mahony 2009).

When the worked hours are weighted according to marginal productivities of each labour type group, the essential labour composition variable can be calculated. Labour composition represents the growth rate of labor quality (index). For example, a shift in the share of hours worked by low-skilled workers to high skilled workers is typically supposed to lead to a growth of labour services. The term of labour services ($\Delta \ln L_j$) is implicitly assumed to be greater than the growth in total hours worked (Report on Finnish labour composition and improvements in SUT calculation 2009). However, that is not always the case in reality. The difference between aggregate measure of labour services and total hours worked, in industry *j*, is captured by labour composition term as follows:

(4) $\Delta lnLC_j = \Delta \ln L_j - \Delta lnH_j$

The term $\Delta lnLC_j$ represents the difference between weighted and unweighted growth rates of hours worked and expresses, thus, any structural changes that have occurred in the hours worked by labour force. For example, the change in education level is captured by labour composition term, if the relative share of hours worked by high skilled employees increases or, if their relative wage inflates.

The effect of labour composition and hours worked can be examined separately or they can be summed up to one total labour services term. Also, the contribution of each subgroup (age, gender and education) can be separated and inspected, but it does not belong to the scope of this thesis and is a matter for another research project. A detailed analysis regarding contributions of each component of total labour input based on Finnish data was performed by Roponen (see Roponen 2010).

2.1.1 Contribution of labour input to value added

The contribution of labour services for industry level is calculated based on the equation (2).

Labour input is defined as a Törnqvist volume index. The aggregated measure of labour services (ΔlnL_j) is weighted by two-period average share of labour compensation in total valued added ($\bar{v}_{L,j}$) of the industry j. Firstly, the quota of aggregate labour services is constructed for each industry j. Then, the weights constructed of shares of labour compensation of total value added in this industry are calculated. The achieved estimate is the contribution of labour services to value added for industry *j*. (OECD: Measuring Productivity manual 2009)

2.2 Capital input

In productivity analysis capital input is measured by "flow of capital services". There is enormous heterogeneity in different capital assets and this implies that they also might have quite distinctive productive characteristics. As a classic example, a computer has a much shorter service lifetime compared to a commercial building but relatively high marginal productivity per dollar invested in it. To make productivities of different assets comparable, the accurate measures must be made. (Jorgenson *et al.* 2005) This is crucial because in the end, we want to achieve the correct and comparable contributions to growth in value added and to labour productivity.

2.2.1 Capital stocks used in National Accounting

There are many ways to measure capital. In the national account framework, there are three sets of capital stock that can be derived: net, gross and productive capital stock. Although the data for all of these three stock series would be available, the usage of each depends on the measure, which is desired to be unveiled. Roughly speaking, the purpose of capital stock measurement can be divided into two sections: a measure of wealth and income (net stock and gross stock) and a measure of the contribution of capital to production (productive capital stock) (OECD: Measuring Capital manual 2009).

By definition the consumption of gross capital stock represents the value of the stock, which producers have in their possession – and is still in use – at time point, *t*. The gross stock is valued in such prices as if the stock was new. This means that, this stock calculation method does not take into the account the age nor the real condition of the capital. When the life cycle of an asset ends, it is withdrawn from the capital stock. As for, the net stock, it does take into the account the depreciation of the rest of the capital. However, the net stock does not suit very well into productivity analysis, since it represents the net asset value. It does not capture the efficiency of the assets included in the capital stock. The point worth noticing is that the value of an asset will decline as its life cycle converges to an end and the future returns diminish as well, but the efficiency of an asset can remain the same through its lifetime. (Aulin-Ahmavaara, Jalava 2003) In productivity analysis, such measure of capital stock is needed, which takes into account the ageing of an asset but also captures the changes in efficiency.

The productive capital stock is used in productivity analysis. It must be highlighted that this measure is not just an add-on to measures of the net capital stock, but, instead, has its own analytical counterpart. For example, the one important element, which productive capital stock entails, is the age-efficiency profile. The age-efficiency profile (age-efficiency function) portrays a loss in the productive efficiency of an asset as it ages. The past investment flows must be corrected for retirements and for the loss in productive efficiency. When this is done, their cumulative value equals to the productive stock. (OECD: Measuring Capital manual 2009)

2.2.2 Capital input and its components

In this subsection, the main components to from a capital input are presented. To give an overview, this section begins with an illustration of capital input composition, which is followed by a detailed explanation. Figure 1 illustrates the process of formation of the capital services, which is a measure of capital input in productivity framework.

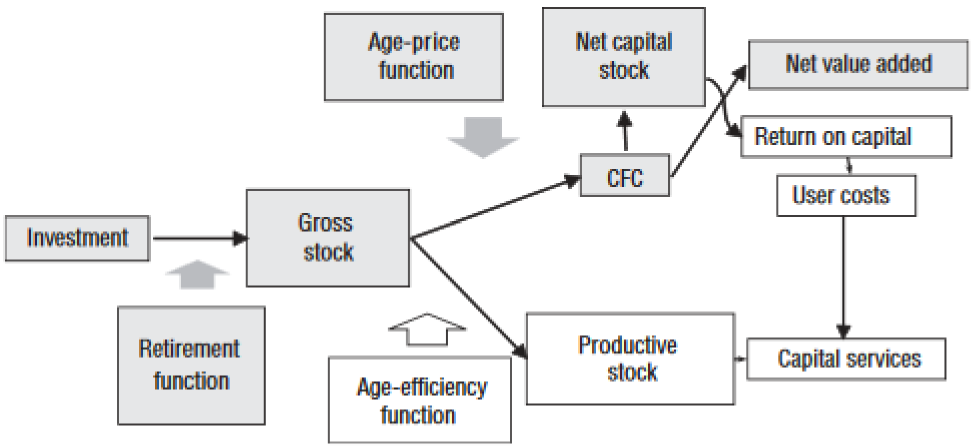

Figure 1. Formation of different capital stocks. (OECD: Measuring Capital manual 2009)

Figure 1 displays the different concepts of constructing capital stocks. Here, the interest is on the productive stock and on capital services that are formed on the basis of the productive capital stock. Firstly, data for investments is gathered. To achieve the measure of gross stock, the investment data are handled with retirement patterns. After obtaining gross capital stock series, the age-efficiency profiles are added to the picture. When the past investment flows are corrected for retirements and loss in productive efficiency, their cumulated values represent the productive stock. By applying certain elements, such as rate of return of capital and price on obtaining services from capital use (user costs), the capital services are accessed.

2.2.2.1 Productive capital stock

The productive stock is, first of all, a vehicle to derive the desired measures of capital services. There are many different types of assets used in production in economy. Each type of capital asset must be taken into account, since different types of capital have a different impact on productivity (Edquist, Henrikson 2015). It is also highly important to consider different life cycles and efficiency profiles of different assets. If this stage fails, then long-living assets, such as buildings, would get the highest weights and, thus, the comparison between contributions of e.g. software assets, which have a much shorter life cycle but might have a crucial impact on productivity, and buildings would be pointless.

The method used to construct the productive capital stock, is Perpetual Inventory Method (PIM). The main concept in PIM is that, the productive stock is defined as a weighted sum of previous productive stocks of a particular asset. The weight for a productive stock at year, *t*, is the proportional (age-) efficiency profile (see, for example, Statistics Finland productivity measurement manual 2010 or OECD: Measuring Capital manual 2009). The formula for constructing the productive stock for each asset is:

$$(5)\ K_{k,t} = \sum_{\tau=0}^{\infty}(1-\delta_k)^{\tau} I_{k,t-\tau} = K_{k,t-1}(1-\delta_k) + I_{k,t}$$

- , where $K_{k,t}$ is the productive capital stock for asset *k,* at year *t.*
    - $K_{k,t-1}$ is the productive capital stock for the same asset in the previous year
    - $I_{k,t}$ is the real investment at current year *t.*

According to Jorgenson, Stiroh and Ho (2005), the interpretation of the equation (5) is that productive capital stock is a weighted sum of past investments, where the weights are deducted from the age-efficiency profile that, in own turn, is determined by geometric depreciation rate. This stage is done for each asset type separately.

In the method used in this thesis, the productive capital stock is calculated following the OECD Manual (2009) guidelines. The productive stock is constructed for each type of asset used in production in Finland. The depreciation rates used in formulation of productive stock differ from the ones used in National Accounting. The depreciation rates used in this thesis are received directly from EU KLEMS. Past investment for every type of asset is cumulated after correcting for the efficiency loss that has occurred since it was new.

3.2.2.2 Capital Services

As a preview, at this point it seems suitable to emphasize the difference between installed capital stock and the service flow of that installed capital stock. The main conceptual difference lies between the stock and the flow. Furthermore, each stock has usually some acquisition price. It is the cost of purchasing the asset. In contrast, the *service flow* is associated with a rental price, which is the cost for renting some asset for agreed period of time. In an example presented by Jorgenson, Stiroh and Ho (2005) one can either buy an equipment for its acquisition price and receive the flow of services through the lifetime of this asset or one can lease the desired equipment and receive the productive service for the leasing time. The distinction between flow and stock is crucial for the successful measurement and aggregation of capital input. (Jorgenson, Stiroh and Ho 2005)

The cumulative productive stock, presented above, represents the installed stock of capital. Conversely, in productivity analysis we are interested in, how capital contributes to the production process. That is, we are interested in the flow of capital services produced by installed stock over some given period of time.

To transform the capital stock to capital service flows for each asset type k, additional elements must be calculated. The most crucial step, is to capture the different contributions of assets to capital services. For this purpose, the concept of user costs is introduced into the calculations. To understand the idea, firstly, a more general concept is presented. Then, the methodology used to achieve the detailed capital services is presented (see subsection **Capital services of each asset)**. The productive capital stock is computed for each asset in each of the 63 industries and for each year.

General approach to capital services (i.e. aggregated capital services)

To achieve aggregate capital service input, the separate productive capital stocks must be weighted accordingly to reflect the marginal productivities of each asset correctly. To obtain the correct contribution of each asset to overall capital services the additional weight shares must be calculated. The assets can be aggregated to one capital service flow element as a translog quantity index. The calculation is done in the following manner:

(6) $\Delta lnK_{j,t} = \sum_k \bar{u}_{k,j,t}\, \Delta lnK_{k,j,t}$

, where $\bar{u}_{k,j,t} = \frac{1}{2}\left(u_{k,j,t} + u_{kj,,t-1}\right)$

The term $\Delta lnK_{j,t}$ stands for capital services on industry level. This term reflects the total capital services produced by all assets in industry *j* during a particular time *t*. The term $\bar{u}_{k,j,t}$ represents the weights given by the average shares of each component in the total value of capital compensation of industry *j*. The term $u_{k,j,t}$ represents the compensation share of each asset group and is closely related to the user cost of each asset. The calculation and interpretation of user costs and elements related to that calculation are presented in the following paragraphs.

Capital services of each asset

The capital services for each asset reflect the contribution of this asset *k* to overall capital services. In this thesis, six groups of assets were computed and for each of this groups the productive stocks were calculated and using weights, accordingly, their capital services were achieved. Regardless whether the assets are inspected individually or in groups, the contributions must sum up to overall level $\Delta lnK_{j,t}$(eq.6). Later equations shall clarify the procedure but, to get the idea, only selected groups are introduced:

(7) $\Delta lnK_{ICT,j,t} = \sum_{k\in ICT} \bar{u}_{ICT,k,j,t}\, \Delta lnK_{ICT,j,t}$

(7.1) $\Delta lnK_{R\&D,j,t} = \sum_{k\in R\&D} \bar{u}_{R\&D,k,j,t}\, \Delta lnK_{R\&D,j,t}$

(7.2) $\Delta lnK_{O,j,t} = \sum_{k\in O} \bar{u}_{Ok,j,t}\, \Delta lnK_{O,j,t}$

The equations show that each asset group is aggregated to industry level using appropriate weights. The weights are constructed analogically as in case of one total capital services input. The average share weights ($\bar{u}_{x,k,j,t}$) are achieved using the compensation shares of each asset type respectively($u_{x,k,j,t}$). Here, e.g., the shares of each asset type of ICT capital are out of total ICT capital compensation for each industry. For example, the productive capital flow of software is weighted by two period average shares. The compensation shares ($u_{x,k,j,t}$) are calculated as *software/total compensation of ICT capital* for industry *j*. As in case of total capital input user costs are exploited in calculations for compensations shares to detect the correct productivities of a particular capital asset.

To continue with the ICT example, this procedure is done for computer hardware and other telecommunications equipment and then the indices are summed up to represent the total ICT service flow index $\Delta lnK_{ICT,j,t}$ for industry *j*. In reality, the process described above is executed for each capital group and each asset. Each asset is weighted so that it can firstly be summed up to a homogeneous upper group and then each group is weighted by its two period average share of total capital compensation in particular industry *j*.

The capital services of each asset group must sum up to overall as follows:

(8) $\Delta lnK_{j,t} = \bar{u}_{ICT,j}\Delta lnK_{ICT,j,t} + \bar{u}_{R\&D,j}\Delta lnK_{R\&D,j,t} + (1 - \bar{u}_{ICT,j} - \bar{u}_{R\&D,j})\Delta lnK_{O,j,t}$

The term $\bar{u}_{x,j}$ represents the two period average share of each capital typegroup in total capital services of this industry j. The average shares represented by terms $\bar{u}_{ICT,j}$, $\bar{u}_{R\&D,j}$ and $(1 - \bar{u}_{ICT,j} - \bar{u}_{R\&D,j})$ are equivalent to the term $\sum_k \bar{u}_{k,j,t}$ presented in eq.(6).

User costs

User costs are sometimes also referred to as rental price. According to the definition by the Bureau of Labor Statistics (1983), “user costs represent the amount of rent that would have been charged in order to cover costs of q dollars’ worth of an asset”. User costs describe the costs incurred over a period of time by the owner of a fixed asset or consumer durable as a consequence of using it to provide a flow of capital or consumption services (ILO, IMF, OECD, Eurostat, UNECE, World Bank, 2004, Consumer Price Index Manual: Theory and Practice, International Labour Office, Geneva.). As the quantity component comes from capital stock formation (productive capital stock), the price component is given by user costs. The implication of user costs is that they portray the marginal productivity of an asset.

The approach is based on the same fundamental assumptions as those by Jorgenson and Yun (1991), which rely on arbitrage equation as the fundament to user cost calculations. The arbitrage equation is derived from neoclassical theory of investment. Jorgenson *et al.* (2005) state that in equilibrium, ignoring the uncertainty and adjustment costs, investors will be indifferent between earning a nominal rate of return on a different investment or buying a unit of capital, collecting a rental price, and then selling the depreciated asset in the next period. (Jorgenson, Stiroh and Ho 2005) Replicating the steps of O’Mahony and Timmer, user costs can be calculated according to the following equation (2009):

$$(9)\ p_{k,t}^{K} = p_{k,t-1}^{I} i_t + \delta_k p_{k,t}^{I} - (p_{k,t}^{I} - p_{k,t-1}^{I})$$

- where $p_{k,t}^{K}$ is the rental price of using capital services
- $p_{k,t}^{I}$ the investment price of asset type k at time point t
- i_t is the internal rate of return and δ_k is the depreciation rate of asset type k

The equation (9) states that user costs consist of the nominal rate of return, the rate of economic depreciation and the asset specific capital gains (O’Mahony and Timmer 2009).

As has been brought to light earlier, computing the correct weight for heterogenic assets is crucial in productivity analysis. As assets differ in their productive characteristics, it also implies that some assets deliver a much higher annual amount of capital services. Thus, to achieve the correct contributions of a particular asset group or asset type to capital services, it is highly important to weight them correctly. Returning to the example of high-tech assets and e.g. buildings: the annual amount of capital services delivered per euro of investment in high-tech assets is much higher than that of a euro invested in, buildings. While buildings have a longer lifetime and, thus, a longer productive period, high-tech assets may be scrapped after 5 years. In addition, high-tech, such as ICT, assets have a high user cost due to rapidly declining prices. For example, the user cost of IT-machinery can be 50% to 60% of the investment price, while that of buildings is less than 10% **(**O'Mahony and Timmer 2009). Therefore one euro of high-tech capital stock gets a heavier weight in the growth decomposition than one euro of building stock. These different effects on capital services is captured by the user costs of capital services. (Jorgenson *et al.* 2005 and O'Mahony and Timmer 2009)

Internal rate of return of assets (IRR)

To successfully determine user costs for an asset k, also the nominal rate of return is needed. The IRR is calculated as residual using ex-post method. The nominal rate of return can be calculated as residual, if value of capital compensation, capital gains and depreciation rates are known. (Productivity analysis overview, Statistics Finland, Pasanen 2010) For IRR calculation, it is assumed, that the total value of capital services for each industry *j* equals its compensation for all assets. Computed this way, the IRR is the same for all assets within an industry but is allowed to differ across industries. This method satisfies the assumption of constant returns to scale. The IRR is formed as follows (eq.10) (O'Mahony and Timmer 2009, Jorgenson *et al.* 2005):

$$(10) \quad i_{j,t} = \frac{p^K_{j,t}K_{j,t} + \sum_k (p^I_{k,j,t} - p^I_{k,j,t-1})K_{k,j,t} - \sum_k p^I_{k,j,t}\delta_k K_{k,j,t}}{\sum_k p^I_{k,j,t-1}\delta_k K_{k,j,t}}$$

- , where $p^K_{j,t}K_{j,t}$ is the capital compensation in industry j, which under constant returns to scale assumption can be derived as value added minus labour compensation.
- The second term is revaluation term (change in prices) and the third term is the depreciation term.
- The denominator represents almost the same as the depreciation term, but is calculated using the prices of previous year (*t-1*).

2.2.3 Summary of constructing industry by capital services

This subsection summarizes the methods of computing the capital services. In productivity analysis, capital input is calculated as flow of capital services. Capital services may be obtained by calculating the weighted growth of productive stock for each individual asset ($\Delta lnK_{k,j,t}$). By incorporating the user costs as reflectors of different productive characteristics into calculations, one may achieve the corresponding capital compensation shares for each asset. Using two period average compensation share weights ($\bar{u}_{k,j,t}$) for each asset, all assets may be aggregated to one capital service flow on industry level. In this way, the contribution of each asset type to changes in capital services is captured. As a result, one capital input estimate is achieved for each industry j.

The productive stock for each individual asset type group is computed using perpetual inventory method (PIM) and geometric depreciation profiles were used. The same depreciation rates have been used in this thesis as the ones used in EUKLEMS project. The weights, to first aggregate all assets to industry level, are based on the rental price of each asset, which consists of a nominal rate of return, depreciation and capital gains (O'Mahony and Timmer 2009). The nominal rate of return is determined *ex post* as it is assumed that the total value of capital services for each industry equals capital compensation. Capital compensation is derived as gross value added minus labour compensation and allocated to each asset, accordingly. The method[5] used in this thesis follows the steps of productivity analysis of Statistics Finland and EUKLMES project. (e.g. O'Mahony and Timmer 2009)

2.2.4 Contribution of capital services to value added

To achieve the contribution of capital input to growth in value added on industry level, the previously computed growth rate of productive capital services must be weighted as accordingly as labour input. Recalling the equation (2) mentioned in calculating contributions of labour input, the same procedure is done for industry level capital input (ΔlnK_j). Principally, the aggregated measure of capital services is weighted by two-period average share of capital compensation in total value added ($\bar{v}_{K,j}$) of industry j. In this way, the industry level contribution of capital input to value added is achieved. The contribution of capital is commensurate with contributions of labour input and multifactor productivity.

In this thesis, capital input is disaggregated into several subcomponents: ICT capital, R&D capital, machinery and equipment capital, non-residential buildings and other structures and other capital. Each capital subgroup has been handled on its own. That means that for each asset for each industry at each time point the productive stock, the flow of productive services, the appropriate user costs and IRR have been calculated according to the methodological strategy presented above. This procedure enables the industry level contributions to be studied separately for each asset group.

[5] The method used in this study differs from the one Jorgenson prefers (Jorgenson and Hall 1967 and Jorgenson and Yun 2001, chapter 2) in that it does not account for taxes. Nonetheless, tax consideration would be an important addition as e.g. investment tax credits, consumption allowance, debt/equity financing can play a major role in capital service price framework (Jorgenson *et al.* 2005). For more specific discussion and implementation of taxes into user cost calculation see e.g. Jorgenson and Yun (2001), Jorgenson and Stiroh (2000b) and Jorgenson, Stiroh and Ho (2005).

The weighted total industry level capital input (ΔlnK_j) implies the contribution of all summed up assets to change in valued added for industry j. However, if in the previous phase the asset groups are weighted but summation is not done, the effect of each asset group to value added can be examined separately. When the decomposition is done, each asset group must be weighted according to the capital compensation shares in total value added. Thus, the previous equation (2) can be put in following form:

$$(11) \quad \Delta lnVA_j = \bar{v}_{L,j}\Delta lnL_j + \bar{v}_{ICTK,j}\Delta lnK_{ICT,j} + \bar{v}_{RDK,j}\Delta lnK_{RD,j} + \bar{v}_{OK,j}\Delta lnK_{O,j} + \Delta lnMFP_j^{VA}$$

To give an idea, only three decomposition groups of capital are presented in the equation (11) above: contribution of ICT capital to value added in industry j, contribution of R&D capital and contribution of other capital (the rest), respectively. Each capital subgroup is weighted by two period average share of capital compensation of this particular capital group in value added of industry j (*e.g.*$\bar{v}_{ICTK,j}$). In this manner, the contribution from, for example, ICT capital, to change in value added, is composed.

Two restrictions must be taken into the account. As earlier, all shares of the equation (11) above must sum up to one as follows $\bar{v}_{L,j} + \bar{v}_{ICTK,j} + \bar{v}_{RDK,j} + \bar{v}_{OK,j} = 1$. And the second restriction is, intuitively, that the sum of contributions of each capital group must equal the total contribution of capital services for industry j; that is $\bar{v}_{ICTK,j}\Delta lnK_{ICT,j} + \bar{v}_{RDK,j}\Delta lnK_{RD,j} + \bar{v}_{OK,j}\Delta lnK_{O,j} = \bar{v}_{K,j}\Delta lnK_j$.

2.3 Multifactor-productivity (MFP)

In this section, the measurement of multifactor-productivity (MFP) and sources of measured multifactor-productivity are discussed. This section starts with a brief introduction to MFP and its sources. Then, the theoretical framework of MFP measurement in the concept of growth accounting and interpretations are presented.

2.3.1 MFP and its sources

Put concisely, MFP is the unobserved factor of value added equation, which – by the general assumption– has a significant impact on standards of living and well-being through its substantial contribution to labour productivity. The multifactor-productivity is achieved, when the effects of other input components are taken into account in the value added function.

MFP represents the ability to produce more output with a given amount of scarce resources or to achieve the same amount of output with less amount of inputs. Either way, the MFP can be seen as finding more efficient ways of producing goods and services or increasing the productivity in other ways. Based on neoclassical production function and welfare theory, the growth in MFP can be interpreted as a shift of the production function towards a higher level, and this increases the living standards of an economy. In addition to elevated technological change in industry level analysis, the MFP reflects changes in utilization economies of scale, resource reallocations within the industry or growth in disembodied technology. (Jorgenson et al 2005)

The idea that there is an additional factor affecting the total output in production function is not a recent one. The literature has been interested in this "measure of our ignorance" (Abramovtz 1956) or later called term of "efficiency" (Grilliches 1995) since the early 40´s. However, it was not until the seminal paper by Solow (1957) that the interpretation of the results were made clear and meaning was given to what were formerly relatively arcane index number calculations (Griliches 1995). Solow´s contribution to productivity analysis was highly important, because he provided an economic structure that had earlier been missing from the framework. He integrated the idea of technical change into production function and used the US national accounting data for his analysis (Jorgenson et al 2005). Whereas in earlier models an explicit production function was appealed to interpret the changes in efficiency, Solow´s model starts with an explicit function and derives the implied index of productivity change. (Hulten 2010).

The residual term of multifactor- productivity is commonly used, but there is a synonymous term, total factor productivity (TFP[6]). Conceptually, they represent the same measurement. Here, the term multifactor-productivity is used (MFP).

As literature by Oulton (2016) presents outcomes of earlier surveys by Hulten (2001), there are several different ways in which the MFP can be affected. The changes in realized MFP growth can be due to one or more of the following points:

1. The inputs can be reallocated towards more/less productive uses. This can be done on firm as well as on industry level[7].
2. The changes in measured MFP can occur as a result of scientific work or technical progress. This means that new, better and more efficient ways of producing old goods can be invented or that the value of output is increased due to quality changes or some other improved features.
3. From externalities and scale effect, which includes learning from others or learning by doing. This can also be seen at the firm level (firms adapt technologies from each other) or at the

[6] Multifactor productivity (MFP) is the name given to the Solow residual in the BLS productivity program,replacing the term 'total factor productivity" (TFP) used in the earlier literature, and both terms continue in use. The "F" in both terms refers to the factor inputs of capital and labour, and the "M" and "T" distinguish MFP/TFP from the single productivity indexes Q/K and Q/L (capital and labour productivity). Hulten (2009) suggests, ""M" is, perhaps, preferable to the "T" simply because the latter presumes that all the relevant K and L are counted, which is typically not the case". (Hulten 2009)

[7] This thesis concerns the macroeconomic level of inspection and, thus, the interest is focused on industry clusters and whole economy level efficiency.

industry or even whole economy level (adaptation of new developed technologies in new industries and spillovers from country to another).

4. Due to measurement error; the MFP growth can be mismeasured in such cases where some kinds of assets are ignored or wrongly omitted as also in case of ignorance of quality changes in physical or human capital (as e.g. improvements in usable equipment).
5. Oulton (2016) includes an additional point that could also affect the MFP development over the years. That is the structural shifts in output and demand, which lead to changes in aggregate growth of MFP. These changes in structure can be favourable as well unfavourable. (Oulton 2016)

To summarize the introduction to MFP, it can be concluded that multifactor-productivity is, for the most part, an unpredictable, exogenous term, which is influenced by several procedures. At the end of a chain of reasoning, some political decisions might affect the MFP in the long run (e.g. decisions about supporting particular investments or giving subsidies to encourage the development and innovative activities), also the accuracy of the measurement must be taken into the account, when interpreting the MFP measures. It must be acknowledged that the term includes a lot of unobserved and merged information about technical and scientific development of economy.

2.3.2 Calculation of MFP at the industry level

The calculation of MFP at industry level is based on the same value added equation as was presented in equation (2). However, following the methodological steps of EUKLEMS, the MFP is calculated as residual term for every industry *j*. Former equation (2) is rearranged as follows:

$$(12) \quad \Delta lnMFP_j = \Delta lnVA_j - \left(\bar{v}_{K,j}\Delta lnK_j + \bar{v}_{L,j}\Delta lnL_j\right)$$

All factors of equation (12) are measured as logarithmic growth rates – i.e. first differences $\Delta x = x(t) - x(t-1)$. The MFP estimate is also a logarithmic growth rate. The calculation is done for every industry accordingly. The time index *t* has been suppressed from the equation, but corresponding calculation has been done for every year included in the exercise.

The key idea is that MFP is measured as the residual term; for the industry, j, MFP is measured as the difference between change in value added of industry *j* ($\Delta lnVA_j$) and weighted contributions of inputs to the change in value added $\left(\bar{v}_{K,j}\Delta lnK_j + \bar{v}_{L,j,t}\Delta lnL_j\right)$, in the same industry. In other words, the contributions of capital and labour inputs are deducted from the change rate of value added. As a result, MFP measure is obtained. The data are available for calculating the capital and labour inputs, and from the data of National Accounts (NA) the change rate of value added can be deduced.

2.3.4 Interpretation

In the approach initiated by Jorgenson *et al*. (2005) and incorporated by EUKLEMS project, the MFP growth measures disembodied technological change. The technological change captured by MFP is not the technical change that occurs due to investments in new capital goods. This change is captured by measure of capital input through the use of quality-adjusted prices and user costs as weights in asset aggregation and, thus, is not included in MFP measures. (O´Mahony and Timmer 2009).

Commonly, the MFP growth rate is positive and the idea of "the bigger the better" is embodied. However, in some cases, the MFP growth rates can be negative. As was presented, the MFP captures not only technological change but also the reallocation of inputs, structural and organizational changes. In the short run, it is justified to assume that at a time point *t* the reorganization process might decrease the measured MFP as resources are allocated to the reorganization process. In the long run, the successful reorganization process will generally lead to higher MFP growth. (O´Mahony and Timmer 2009); for a discussion see Basu *et al.*, 2004)

Timmer and O'Mahony (2009) also emphasize that under assumptions of perfect markets, MFP measures pick up any deviations from the assumptions that marginal costs reflects marginal revenues. For example, if ICT investments have not been driven by economic fundamentals, it might be the case that marginal costs are higher than marginal revenues. Consequently, as in growth accounting model marginal costs reflect marginal productivity, the contributions of ICT investments to growth are overestimated and measures of MFP are underestimated. (O'Mahony and Vecchi, 2005). Timmer and O'Mahony (2009) imply this might have been the case behind the ICT boom in 1995–2001.

As MFP is a residual term, it might also contain effects of unmeasured inputs and measurement errors (see e.g. Corrado *et al.*, 2006).In strict neoclassical assumptions, the MFP growth measures disembodied technological change. Based on theory, the negative MFP would yield technological regress. However, keeping in mind the various factors that are incorporated by the MFP term, the negative development of MFP is possible and can indicate diverse development trends and changes.

2.4 Labour productivity: measurement and interpretation

In this section, the labour productivity (LP) from methodological point of view is introduced. Labour productivity calculations lean strongly on calculation of multifactor-productivity, presented earlier, and, thus, the composition of each component is not presented in detail here. Many existing studies suggest that MFP and capital deepening are the two factors that affect the development of labour productivity the most (see e.g. Gomez-Salvador, Musso, Stocker and Turunen 2006). As a detailed composition of capital and labour inputs is presented earlier, they are not presented further. The key idea behind labour productivity calculus is that, when the MFP measure is achieved via previous calculations, it is integrated, as it is, to labour productivity analysis. All other components are divided by amount of hours worked based on definition of labour productivity.

2.4.1 Labour productivity at the industry level

By definition, labour productivity is the output divided by total amount of hours worked. This states how much output has been produced in one hour of work. In this thesis, the labour productivity is defined as the annual change in total value added divided by an annual change in total hours worked. Measures are derived in logarithmic terms and the industry by equation for labour productivity takes the following form:

$$(13)\quad \Delta lnLP^{8}{}_{j} = \Delta lnVA_j - \Delta lnH_j$$

$\Delta lnLP_j$ stands for the changes in labour productivity. The term $\Delta lnVA_j$ reflects the logarithmic annual change rate in value added and the second term ΔlnH_j reflects the annual change in logarithmic hours worked. Recalling, that the change in value added can be decomposed into several subcomponents, it follows:

$$(14)\ \Delta lnLP_j = \Delta lnVA_j - \Delta lnH_j = \underbrace{\bar{v}_{L,j}(\Delta lnL_j - \Delta lnH_j)}_{\Delta lnLC_j} + \bar{v}_{K,j}(\Delta lnK_j - \Delta lnH_j) + \Delta lnMFP_j^{VA}$$

The subcomponents (labour composition, capital input and MFP) are taken directly from the multifactor-productivity calculations. Terms are then corrected to fit the LP calculations and theoretical framework by deducting the logarithmic change of total hours worked at the particular industry *j*. Labour productivity is calculated as a sum of the Törnqvist volume indexes of its individual components. The $\bar{v}_{x,j}$ is the two period average share weight. It is composed of labour or capital compensation (with respect to subcomponents) shares of total nominal value added for industry *j*.

The interpretation of equation (14) above is that the labour productivity is dependable on changes in labour composition, changes in capital intensity and changes in MFP.

[8] $ln\frac{x}{y} = \ln(x) - \ln(y)$

Analogically to MFP calculations, the term of capital deepening ($\Delta lnK_j - \Delta lnH_j$; capital intensity) is decomposed to multiple subcomponents to achieve a better understanding behind contribution of capital to labour productivity. The total capital intensity term consists of contributions of ICT- and R&D- capital intensity, equipment and machinery capital intensity, contribution of non-residential buildings and other structures and contribution of other capital assets (intensity). In this study, the results are calculated for each asset group but due to diminutive contributions only effects of ICT- and R&D- capital intensity, equipment and machinery capital intensity and contribution of non-residential buildings are analyzed.

The weights of labour productivity equation sum up to one, even though each capital subgroup is presented as an independent term. Commonly, capital deepening means an increased amount of capital per worker (in this case per hour worked). Economic growth theories imply that due to capital deepening the economy will expand and the productivity per worker would increase as well.

2.5 Productivity measurement at the aggregate economy level

Previously the calculations were done for each industry. In this section, the aggregation method is discussed. The most precise level of calculation of multifactor-productivity and labour productivity includes 54 industries. To achieve the measures for whole economy level, these results must be aggregated. The achieved measures for aggregate economy level represent the development of whole economy. Through these calculations, the contributions of each industry to some particular measure are accomplished. The results discussed in chapters 4 and 5 are related to the methods presented in this section.

The aggregation method used to aggregate industry by flows of services to whole economy level is direct aggregation. According to the OECD Productivity manual, "the "direct aggregation" keeps the industries as a smallest unit of construction". (OECD Measuring Capital 2009, chapter 17 p.151). The aggregated value added function takes a form as follows:

$$(15)\quad \Delta lnVA = \bar{v}_L \Delta lnL + \bar{v}_K \Delta lnK + \Delta lnMFP$$

The labour and capital inputs are aggregated using two period average value added shares ($\bar{v}_x$) in total nominal value added. That is to say that the measures of capital and labour services from each industry are weighted by two period average value shares. In the case of capital input, each subcomponent is weighted accordingly and the contributions of each capital type to aggregate value added are obtained. In the case of labour input, a separation was made into labour composition and hours worked.

Formulating MFP measure at the whole economy level is done differently. The MFP measure for whole economy is achieved by the same residual method as in industry level calculations.

2.5.1 Aggregating MFP

As the capital and labour inputs were calculated by aggregating the industry measures, the MFP aggregate is calculated as residual. On aggregate level of inspection, the valued added change for each industry j is calculated as Törnqvist indexes, which implies using two period average shares of value added of each industry of total value added.

$$w_j = \frac{VA_j}{VA_{economy}}$$

$$\bar{w}_j = 0.5 * (w_{j,t} - w_{j,t-1}) \qquad (16)$$

$$\Delta \ln V_{total} = \sum_j \bar{w}_j \Delta lnVA_j$$

The final aggregate measure of MFP for whole economy is formed as follows:

(17) $\Delta lnMFP^{VA} = \Delta \ln V_{total} - (\bar{v}_K \Delta lnK + \bar{v}_L \Delta lnL)$

- where the $\bar{v}_x$ is the aggregation weight for each input , respectively

2.5.2 Aggregating labour productivity

Aggregation of labour productivity is executed following the guidelines of Jorgenson *et al.* (2005). It is not as straightforward as the aggregation of MFP and other terms of value added based production function. When incorporating the value added concept of industry labour productivity, the result on aggregated level is presented in the following equation:

(18) $\Delta lnLP = \Delta lnVA_{economy} - \Delta lnH = \left(\sum_j \bar{w}_j \, \Delta lnLP_j\right) + \left(\sum_j \bar{w}_j \Delta lnH_j - \Delta lnH\right)$

Labour productivity at the whole economy level ($\Delta lnLP$) can be calculated as the annual logarithmic change in aggregate value added minus the logarithmic change in aggregate hours worked. Further, by rearranging the eq. (18), aggregate labour productivity can be presented as a sum of aggregated labour productivities from industries and the reallocation of hours.

The first term of the second part of the equation (18) is the direct effect from industry level labour productivity growth. $\Delta lnLP_j$ is labour productivity ($\Delta lnVA_j - \Delta lnH_j$) in industry j. The term ($\Delta lnLP_j$) can be substituted by eq. (14) presented earlier. Values are aggregated to the level of the whole economy using the two period average value added shares of total value added ($\bar{w}_j$).

The second term represents the reallocation of hours worked. The reallocation is a real economic effect that moves resources among industries. The interpretation of this effect is that industries with relatively higher value added experience faster growth in terms of hours worked (Jorgenson *et al.* 2005). The reallocation term $(\sum_j \bar{w}_j \Delta lnH_j - \Delta lnH)$ is computed by deducting the total hours worked in whole economy from the aggregated hours from industry level.

The reallocation term is positive if the allocation of hours had been efficient, i.e. more hours have been worked in industries with higher labour productivity. Correspondingly, if the term is negative, then the flow of hours has been from high marginal productivity industries towards less productive industries.

By definition, the term $\Delta lnLP$ can be expressed as the sum of aggregate labour composition term, aggregate capital intensity and the whole economy level MFP. Each component of labour productivity equation is weighted with two period average value shares in total value added. In this way, the contribution of each component to aggregate labour productivity is achieved. The contributions of each capital subset to aggregate level are detected through aggregate capital intensity. For example, firstly, the contribution of R&D capital, to aggregate capital intensity is obtained. Then, through the effect of aggregated capital intensity, the contribution of R&D capital to aggregate labour productivity is captured. The aggregation weights of each capital subset are assigned accordingly.

3. Data

This chapter provides description of the data used for the analysis in this thesis. The sources of the data and the procedures used to fit the data to productivity analysis framework will be shortly described in this chapter. In section 3.1, the data for labour services calculation are introduced. The data used for capital services calculations are described in section 3.2.

This study concentrates on market economy. The choice to focus on market economy is based on a how well the final output is measured. The idea of well-measured output was firstly introduced by Zvy Griliches in 1994 (Griliches 1994, p.10). The final output can be poorly measured in two ways: the indexes of activity are inputs such as employment (an example of that is the education sector) or the deflation techniques used are potentially defective.

The defective deflation measures might occur when the basket of goods and services of a particular sector is not representative of a wide range of outputs that this sector produces. Thus, price indexes used to deflate the nominal magnitudes do not fully correspond to the products of the sector. This is the reasoning, why the “Real estate activities “industry is excluded. Secondly, it might be the case that underlying price index does not adequately capture quality changes or the introduction of new goods and services in that sector. (Nordhaus 2002)

Industries with high share of public sector are excluded from the study (e.g. Education and Public administration and defense industries). The second reason presented by Nordhaus applies here: since there is no market for goods and services produced by the public sector, it is hard to get adequate prices and capture the relevant changes. The methodology used in this thesis is, therefore, not fully compatible with productivity calculation of public sector.

The most precise level of industry division includes 63 industries. There are, altogether, 54 industries that are included in the analysis. The industries excluded are:

- Public administration and defense; compulsory social security (industry classification code 84)
- Education (industry classification code 85)
- Human health and social work activities (industry classification code 86-88)
- Real estate activities (industry classification code 68)
- Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use (industry classification code 97-98)

Due to reasons explained, it is in the best interest of this study to exclude the industries mentioned as it would provide a more realistic total picture of the development of MFP and labour productivity in Finland.

In the breakpoint of the year 2000, there were several major changes in methods used for measuring economic activity. The most important changes that had an impact on productivity research were the changes in deflating the nominal series. After the year 2001, the National Accounts began to practice double deflation methods in measuring the output and intermediate input. Previously, both of the series of intermediate input and value added have been assumed to follow the trends of volume of output. In 2001, the measures for fixed priced output and intermediate input have been done separately. This influenced the supply and use tables and thus affected also the productivity studies.

During that time, based on the decision of the EU commission, the methods to calculate the volume changes in non-market services were modified. In previous the method, the costs were deflated and productivity was assumed to be constant. The decision of the EU commission led to the usage of the volume-indicators, which brought changes in assumptions used and in methods executing the measurement. Due to changes in the assumptions and the difficulty to detect the correct prices for public services, using the methodology pioneered by Jorgenson leads to negative development of productivity in public sector. The negative development can be detected in Figure 2.

As it can be seen from the Figure 2, the total level of labour productivity is lower than the level of private sector alone. The negative productivity of the public sector might not be the real case, but is instead an indication that a different methodology must be used to measure productivity in the public sector. To get a more precise picture of the state of the economy, excluding the particular industries seems reasonable.

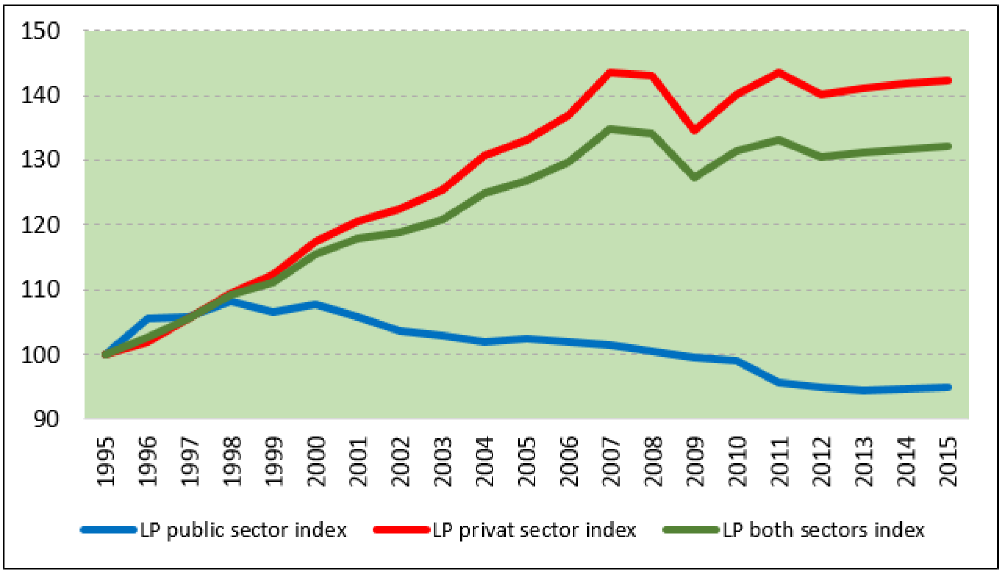

Figure 2
Development of labour productivity in private and public sectors (index 1995=100).

It must be acknowledged that due to methodological implementations in measuring indicators of economic activity, the time series are not exactly comparable. As this thesis inspects the period of 1995-2015, the first six years are not fully comparable with the rest of time series. This does not have a major effect on the overall analysis, but it is a point to keep in mind. However, the years 1995-2001 are important for the analysis, since the year 1995 can be seen as a threshold for the commercialization of the Internet. Therefore, it is justified to include this time period in the analysis.

3.1 Data for labour input

This section introduces the sources used for gathering data for labour input calculations. The data for computing labour services are gathered from Employment Statistics, which have important population census features. The data are linked to correspond the total amount of hours worked and the total amount of labour compensation from National Accounts.

Employment Statistics are annual statistics providing data on the population's economic activity and employment. The population for the statistics is the permanently resident population in the country on the last day of the year. The data are mainly derived from administrative registers and statistical data files. The unit-specific data of the employment statistics are confidential by virtue of the Statistics Act. (Report on Finnish labour composition and improvements in SUT calculation 2009) The data describe the main type of activity of the population, and the industrial distribution, numbers and locations of workplaces in the country, and the occupational status, educational level and income of the population. (Report on Finnish labour composition and improvements in SUT calculation 2009)

The Employment Statistics, therefore, include information on the total amount of months worked, employees and total labour compensation payed by industry. The data are available for several age-groups, education levels, both genders and both occupational status (is the person self-employed or not). Thus, the data represent the total amount of employed males aged 30-54 years who have a, who have master's degree and work in the field of "Manufacture of computer, electronic and optical products". For implementation of this data to productivity analysis framework, some additional assumption had to be made. Calculations in this thesis replicate the ones used in Productivity analysis of Statistics Finland.

Data obtained for the calculations were received for the years 1987-2014 on the numbers of employees and self-employed and on months worked by the employees and the self-employed. The data were cross-classified by industry, gender, age and education. Data on wages in euro were received for employees and self-employed for the years 1987-2014. The data on the wages of the self-employed were not used in these calculations. The data on the wages were also classified by industry, gender, age and education. (Report on Finnish labour composition and improvements in SUT calculation 2009). The estimates for the last year, 2015, are calculated based on distribution of 2014 and are therefore approximations.

The industry level labour input (ΔlnL_j) is cross-classified by educational attainment, gender and age with the aim to proxy for differences in work experience and to capture the differences in productivity. The baseline data are divided into 18 (3*2*3) compensation groups or also referred as labour type groups ($\Delta lnH_{l,j}$). The groups consist of two genders, three age groups - 15–29, 30–54 and 55+ - and three educational groups: "no post-basic education" (LS = low-skilled), "secondary education" (MS= medium-skilled) and "higher education" (HS=high-skilled).

To assign the hours worked correctly to compensation groups, two sources were used. The newest available data on hours worked were attained from the latest publication of National Accounts. The distribution for number of employees and self-employed by compensation group was gathered from employment statistics. In the Employment Statistics, the worked hours by each occupational status are distributed according to numbers of employed. The NA industry by data on hours worked for employees and self-employed was distributed to compensation groups by using the distributions from Employment Statistics.

The distribution of labour compensation for employed to compensation groups is assumed to be the same as the distribution of income for employed from Employment Statistics. Due to data-limitation of self-employed, the distributions of wages are assumed to correspond to the distribution of employed belonging to exactly the same labour type group. For example, a high-educated self-employed 30-54-year-old woman, who works in the field of “Manufacture of textiles” is assumed to get the same wage as the woman of exactly the same demographic characteristics but, who works as employee. Employers' social security payments were not included to the labour compensations.

3.2 Data for capital input

The data for calculations of capital services ($\Delta lnK_{j,t}$) are obtained from National Accounts' base of investments. The investment data are used to construct the productive capital stock (this step refers to equation (5), the $I_{s,t}$ represents investments in each asset). Altogether, 14 assets are included in calculation of this thesis. As the topic of this examination is concentrated around contribution of capital to labour productivity and to changes in value added, a more precise division has been made for capital assets than is usually the case in the field of productivity research. The division most commonly used in this type of research categorizes assets in 2-3 groups as ICT capital and other capital assets or ICT capital, R&D capital and other capital assets (see for example Inklaar, O´Mahony and Timmer 2005 or Edquist and Henrekson 2015).

As Jalava and Aulin-Ahmavaara point out (2003), some assets are hard to consider as production factors, but they might have a high share in the productive capital stock or in other stocks of capital (gross capital stock or net capital stock). Thus, some assets might have a considerable contribution to productivity growth or change in value added but are not easy to interpret in any reasonable way. Residential buildings are commonly considered such an asset. For reasons mentioned above, Jalava and Aulin-Ahmavaara (2003) exclude the residential buildings from their research. However, if the exclusion of residential buildings is made the according share – owning of residency and renting value – must be removed from gross value added (Aulin-Ahmavaara and Jalava 2003).

Since dwellings are mainly in one industry, Real estate activities (Industry classification code 68), the problem of residential buildings has been solved by excluding this industry. The exclusion doesn’t create asymmetry between the input and output and, based on the assumption that dwellings contribute mainly on Real estate industry growth, it must be that contribution of dwellings is zero in all other industries. However, as in this study the capital is disaggregated into several capital groups, it would be possible to achieve the contribution of dwellings, at will.

In this exercise, 14 types of assets are included. The assumption is made, that the 14 assets exist for each industry. Conceptually there are, hence, 54 industries and each one has 14 types of assets summing up to 54*14 (756) assets altogether. This is an important fact to notice, since the differences in the used assumptions affect the method used for aggregation further on. The method of aggregation used in this thesis is the direct aggregation across industries. The main assumptions used by this method are:

1. Each industry has its own value-added (production) functions. That, however, does not mean that the functions are exactly the same.
2. Releases the assumption of equal prices across industries, which implies that the same asset in each individual industry j differs in the productivity.

Conceptually, it can be put as each industry has its own set of 14 different assets. The productivity of these assets varies across industries and is reflected by user costs (the term $p_{k,t}^{K}$ in equation 9) of each capital asset. The user costs are based on asset prices and are discussed in detail in the section of composing capital services. The main implication is given by the assumption that in perfect market conditions the occurrence of equilibrium equates the marginal productivity and price paid for achieving this productivity. Thus, the prices reflect the marginal productivity of an asset.

The assets included into this analysis are equivalent to those available in the statistics of National Accounts (excluding the raw data on ICT equipment). For sake of data and privacy policy protection and to improve the quality of analysis, the included assets were classified into 4 groups:

1) Other structures and non-residential buildings
2) Machinery and equipment assets
3) ICT capital assets; this group includes software and other information technology equipment.
4) Research and development capital (R&D)

As in case of labor services, the industry classification and other related classifications are linked to asset groups.

3.3 3 Cautionary matters

This thesis relies strongly on methodological strategy of measuring productivity used by OECD and EUKLEMS projects. Especially, it has been emphasized, that the framework of EUKLEMS project and dataset has two great strengths. Despite the fact that EUKLEMS dataset is not used in this thesis, it must be mentioned that the framework inspired by this project has its advantages. Firstly, the manner of gathering data for analysis is consistent with the National Accounts (Oulton 2016). As it is here, the data are based on National Accounts of Statistics Finland. Secondly, the comparability between studies based on EUKLEMS database and methods is on a high level due to common methodology for estimating labour and capital services and measures of labour quality. However, this section will focus on implementation issues that have been noticed and other cautionary matters when applying the methodology. In addition, suggestions on interpretation of results are presented.

The EUKLEMS framework is rather demanding in terms of data. Before the EUKLEMS-project, many countries, including Finland, did not have the appropriate data to suite the EUKLEMS framework. This led to a need of constructing and incorporating new calculation methods to NA framework (see EU KLEMS growth and productivity accounts Version 1.0 Part I Methodology. 2007).

For example, the fixed and current priced supply and use tables for Finland for the period of 1970-2000 were constructed in collaboration of EUKLMES productivity project (Statistics Finland productivity manual 2010, p. 26). Due to incorporation, methodological and calibrating issues, the "volume change of value added" series before the year 2001 are not fully comparable to latter series (the latter part is constructed using double deflation and the former is mostly constructed implementing single deflation). Furthermore, at the beginning of the 21st century, there has been a change in, how the output is measured (Kansantalous 2006). The changes might not be significant, but this is still a thing to keep in mind, when analyzing and comparing the results from different periods.

Another matter of caution is deviation from basis of EUKLEMS guidelines in calculating value added. The approach of Statistics Finland productivity surveys has been taken in this thesis. The data, used to calculate value added, is based on output. In other words, value added series are calculated by subtracting the intermediate input from output. Another possible method would be to use the value added series directly from National Accounts.

4. Economic growth and labour productivity

The chapter 4 presents the results on aggregate economy level. Consistent with the methodology, the contributions of each relevant factor on the development of economic growth and the development of aggregate labour productivity are inspected and discussed. In both cases, the main focus is, however, on the disaggregated capital services and the MFP measure.

The section 4.1 discusses the aggregate development of value added during the periods of 1996-2005 and 2006-2015. The following section 4.2 examines the changes in aggregate labour productivity. The section 4.3 concludes with the summary of the results on the aggregate level analysis.

In both subchapters 4.1 and 4.2, the timeline is divided into two periods. The coverage of each period is 10 years. It is relevant to notice that to minimize the unwanted variation in time series, the time periods are set to begin and end in consensus with the ongoing economic cycle; for example, the period 1995-2005 captures the cycle of upward economic trend, whereas the period of 2006-2015 includes the time of the 2008 financial crisis and the stagnation of growth that followed. This kind of division is done to avoid the effects of other possible exogenous shocks and to improve the comparability of the results.

When the periods are scheduled at the same turning points of the business cycle, the effects of fluctuations in capacity utilization rates are as low as possible. The two periods in this study are carefully selected and thought to represent the intriguing changes in production and labour productivity factors in the Finnish economy. The unwanted fluctuations dilute as the first period 1996-2005 can be seen as the business cycle of "good period" and the latter period 2006-2015 closes up the cycle of negative development. When focusing on two longer periods, the differences and the changes can be seen more clearly and the important information about structural changes in the development of economy can be discovered.

4.1 Contributions to aggregate value added

Based on neoclassical production function, the change in value added consists of the sum of three factors: the contributions of capital and labour inputs and MFP. In Table 1, both primary inputs are disaggregated to several subcomponents. The disaggregation of labour input is crucial for further analysis of labour productivity. Labour composition (LC) and contribution of hours worked can be summed up to represent the total contribution of labour input.

In the following section, the results on contributions of each input factor to value added are presented. Consistent with the theory, the important measure of MFP is achieved as a residual term via the difference between the value added and capital and labor inputs.

Table 1 represents the contributions of each input factor to changes in value added. Following measures are calculated for the economy of Finland as one whole unit (= aggregated level of market economy). The presented values for each period of time are average logarithmic growth rates. That means, e.g., that the average annual change in value added during the period of 1996-2005 was approximately 4.8 % and each input factor has affected the growth by the values (logarithmic %-points) presented in Table 1. The values can be interpreted as, e.g., the multifactor-productivity has contributed 2.56 logarithmic %-points to the change in value added during the period of 1996-2005. The third column of the table represents the difference between the values of "good" and "bad" cycles.

The measure of total capital input presents the total contribution of all capital assets in the economy and arises from the sum of other asset groups presented in the table. For example, the contribution of ICT capital is captured by total capital input, but it can be also stated that ICT capital has contributed 0.38 logarithmic %-points to the change in value added in the period 1996-2005.

The contributions of "other capital assets" and of "residential buildings" were dropped from the analysis. It is assumed that there is no contribution of dwellings in any other industries apart from "Real estate activities" (Industry classification code 68), which was dropped from this study. "The contribution of other capital assets" includes such assets as "costs of ownership transfer on non-produced assets", "intellectual property products", "animal resources" and "originals of entertainment, literary and art", contribution of which was during all periods insignificant (on average mostly zero). For these reasons, the assets in question were excluded from the analysis.

Table 1
The factor contributions to the value added growth of the Finnish non-residential market sector.

	1996-2005	**2006-2015**	**diff.**
Value added	**4.76**	**0.14**	**-4.62**
Total capital input contribution	**0.99**	**0.34**	**-0.64**
Contribution of ICT capital	0.38	0.21	-0.17
Contribution of R&D capital	0.56	0.11	-0.45
Contribution of machinery and equipment	0.06	-0.01	-0.07
Contribution of Non-res.build.and other structures	-0.02	0.04	0.05
Total labour input contribution	**1.21**	**-0.04**	**-1.26**
LC contribution	0.14	0.13	-0.01
Contribution of worked hours	1.07	-0.17	-1.24
MFP	**2.56**	**-0.17**	**-2.73**

Note: the presented estimates are average annual growth/contribution rates of periods 1996-2005 and 2006-2015.
The third column (diff.) represents the differences between the period 2006-2015 and 1996-2005.

A quick glance at the table reveals some very important points. Firstly, there has been a dramatic decline in the growth rate of aggregated value added. The difference between average growth rates of value added is enormous -4.6 percentage points. Secondly, one of the main reasons for such a sharp decline is the collapse in the growth of multifactor-productivity. The results in Table 1 are contributions of each factor to aggregate value added, however, it must be remembered that one of the main outputs of this phase is to achieve the measure of multifactor-productivity, which has a crucial role in the analysis of labour productivity later (Table 1 refers to eq. (15) and (17)). In the following paragraphs, I discuss the contributions of each factor to value added and contemplate the results from the two time periods presented.

As it can be seen from the first period, the MFP has had a significant impact (2.6 log %-point) on the growth of value added. Recalling the meaning of MFP, the measure of MFP includes the technical and technological changes, the restructuring of economy, which enhances the production process and the more efficient and innovative way of achieving the same value by less inputs or, alternatively, by using less inputs to achieve greater value of production.

The second largest contribution to the growth of value added is attributed to total labour input, which consists of hours worked and labour composition term. As was determined in the methodology section of this thesis, the total labour input is measured based on the assumption that wages reflect the marginal productivity. Due to an accurate weighting procedure, the workers with higher earnings have also a higher impact on the total labour input. In practice, this means that if the higher paid employees work more hours, the index of labour input would react more strongly to this phenomenon than if the same increase would occur in hours worked by those with a lower wage.

The increase in labor input is affected not only through changes in hours worked, as hours worked can remain just about unchanged, but it might also occur due to increased relative share of high skilled and thus higher paid workers. The marginal product of labor increases, when less skilled worker become more skilled and their relative income increases. This change is captured by the labour composition term (also referred to as labour quality index), which captures the heterogeneity of labor force. Since the labour quality index is defined as the difference between growth rates of total labour input and hours worked, this term expresses the structural change in hours worked.

The contribution of total labour input was 1.2 %-points and within this measure the greatest contribution to the growth can be detected in factor of hours worked. The contribution of (unweighted) hours worked was 1.1 %-points and it represents the average contribution of value produced by all labour groups in the Finnish economy during period of 1996-2005. Labour composition term includes all the structural changes in labour force and can, for example, project structural changes such as aging of labour force and retirement of postwar born generations. The contribution of labour composition term is, however, a modest 0.14 logarithmic percent.

In contrast to the “glorious” period 1996-2005, the latter period 2006-2015 can be characterized as the cycle of stagnation of growth and inefficiency of production mechanism. Almost all input factors have decreased and some have even taken a dive below zero. The average growth of value added during the past 10 years has been on average only 0.14 %. The biggest factor that has caused the slowdown is the sharp decline in MFP, which has shown signs of stagnation over the period 2006-2015.

All input factors have turned negative except the contribution of capital services. The contribution of MFP was -0.17 %-points and the contribution of total labour input was only slightly negative being -0.04 %-points. The negativity of total labour input is clearly attributed to sharp decline in contribution of hours worked, since the labour composition term remained positive 0.13 %-points. The economic growth during the period 2006-2015 can be mostly assigned to growth of capital. Capital services have contributed to the change in value added as high as 0.34 %-points.

Comparison of these two periods reveals the excessive impact of the post 2008 crisis and the economic breakdown. When comparing these two periods, the major declines are seen in primary inputs and in multifactor-productivity. Mostly due to decline in MFP, a sharp decline in value added occurs.

Contribution of total labour input has turned negative. The interesting part is that the labour composition term has remained almost unchanged, which indicates that despite the changes in economy such as digitalization, aging of population and the 2008 financial crisis, the structure of labour input has remained somewhat constant. In this context, this can be seen as a positive sign, since the effect of labour composition term is positive. One could speculate that the returns on education have remained affirmative (i.e. the average impact of higher educational level on the economic growth) but this argument would, however, require a further analysis and deeper disaggregation of labour quality term and this lies outside the coverage of this study.

The diminishing contribution of overall labor input term is caused by the breakdown in hours worked. The Figure 3 represents the annual contributions of (unweighted) hours worked and the labour quality term. The changes are annual logarithmic %-changes. As can be seen in Figure 3, the series of hours worked is heavily affected by the effect of the post-2008 crisis. This measure is highly sensitive to fluctuations during business cycle. Thus, such shocks as a depression can affect the hours worked and the contribution of this measure quite significantly. In contrast, the measure of labour composition is not influenced in the same manner by the changes in economic situation. The first period 1996-2005 does not include any recession periods, whereas 2006-2015 captures the negative effects of the financial crisis. The layoffs occurring during this latter period could provide a plausible explanation for negative contribution of hours worked during the period.

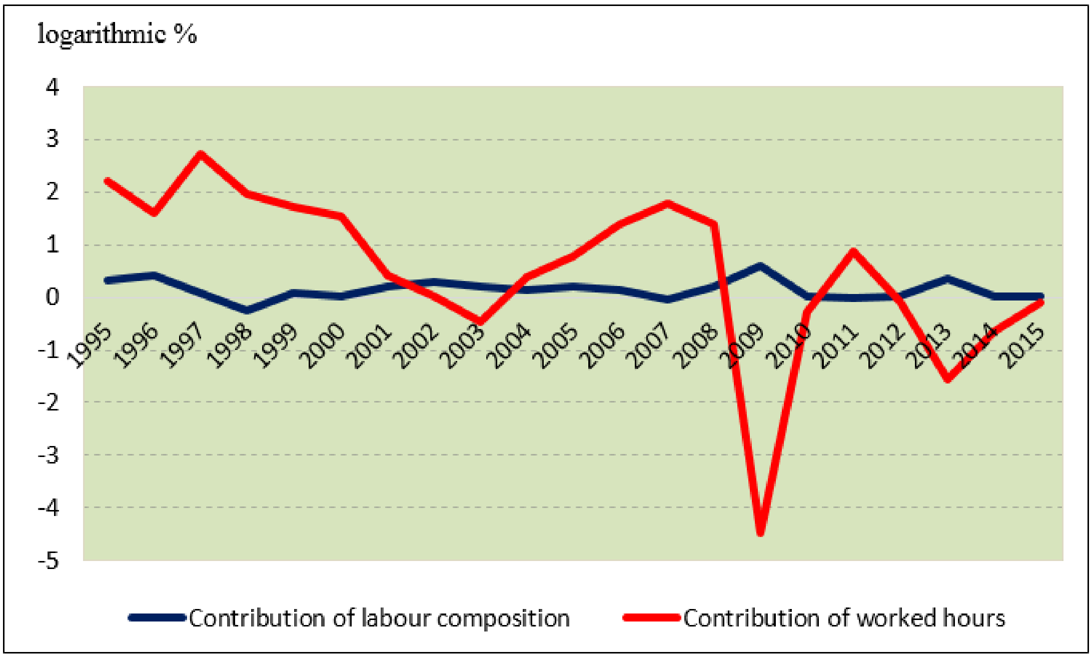

Figure 3
Contribution of hours worked and labour composition term to aggregate value added growth.

The total contribution from capital services has undeniably declined when comparing these two observation periods, but it has still remained positive. In latter period, the contribution is still relatively high, although the reduction verges towards 65%. Recalling the methodology incorporated in this study, the calculations of capital services rely on user costs of each capital type. The accurate weighting scheme takes into account the different age-efficiency profiles of assets, therefore, the products such as computers receive higher weights based on their higher marginal products. This method leads to full comparability of contributions of different asset types.

Further, the disaggregation of capital exhibits that the highest contributions come from ICT and R&D capital. Combined with the theoretical approach this result indicates a shift inside the total capital input. The shift can be interpreted as substitution towards capital with higher productive properties. This is not a surprising result, especially for the period of 1996-2005. The great contribution of Nokia was conveniently during this. The high contributions of these capital sets are not only due to Nokia, but Nokia was surely a great incentive.

Although there is a decline in contribution of each group of capital services, the steepest decrease is seen in contribution of R&D capital. The deterioration is close to 80%. On average, the contribution of R&D capital was 0.56 %-points in the first period, but in the period 2006-2015 it was only 0.11 %-points. When comparing the former period to the annual contribution rate of 2015, the picture is even more melancholic, since the contribution of R&D capital in 2015[9] was -0.10 %-points. The difference between the two inspection periods is -0.45 logarithmic %-points.

Caution needs to be taken when studying the contribution from ICT to growth of value added. The data acquired for calculating stocks of ICT capital might not be of the best quality. Statistics Finland uses certain principles for calculating missing data for ICT stocks. It follows, that ICT capital data are partly methodologically derived and thus, might not fully reflect the actual changes. However, it is the “first-best option” and at the present moment the best way of gathering information on this matter. It must be noted that the initial contributions might have been induced by these acquisition principles and shall be interpreted with caution.

Even if the contributions of ICT capital are not precise, there is no doubt that in the period 1996-2005 this set of capital had a progressive effect on development of value added. It is also rational to assume, that the contribution of ICT capital is slowing down, since it might be that the economies worldwide are on the edge of digitalization breakthrough and the pure investments in ICT capital and purchasing computers and other information technology devices is not the prime goal. ICT devices have become normal goods and the prices of acquisition have made the purchase possible for a larger audience. The changes in contributions of capital to value added for the whole observation period can be seen in Figure 4. The Figure 4 shows the annual contributions of each asset type to aggregate value added in percentage points. The overall trendline represents the contribution of total capital input on aggregate value added and is the sum of subgroups of capital.

The Figure 4 unveils the compelling role that R&D capital had on the economic growth of the Finnish economy in the former part of the whole observation period. These data show that there has been a shift from more traditional fixed assets towards ICT and R&D capital. For the whole period after 1995, the effects of these capital types to aggregate value added have been significant. It can be stated that in the first period 1996-2005 the firms had changed their investment patterns and had evidently responded to the acceleration of price decline in ICT and R&D capital by changing their investment patterns. The ICT-boom in the 90´s is seen as the stronger contribution of this capital type for one's

[9] Full data for period 1995-2015 is available in Annex.

part due to a more rapid accumulation of computer and other information and communication related capital.

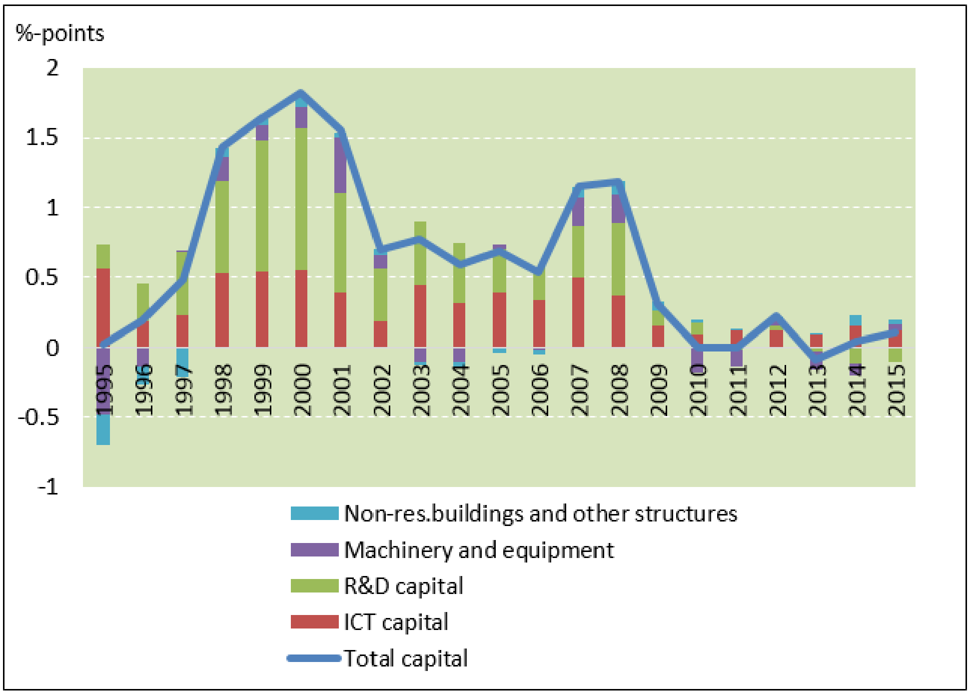

Figure 4
Contribution of capital services to growth of aggregate value added.

A more dramatic picture is portrayed by Figure 4. The Figure 4 presents the average contributions of total and disaggregated capital. The same drastic fall is seen here as in Figure 4. Especially, the declined contributions of all asset types emerge in comparison of time periods of 1996-2005 and 2006-2015. The Figure 5 reveals this picture in detail.

The decline of total capital input in the latter period of 2006-2015 is mostly due to reduction in R&D capital. Both Figures (4 and 5) picture the dismal development of contribution of R&D capital in in the years following 2008. After the year 2008, the contribution of R&D capital has dramatically dropped from former level[10] of 0.51 percentage points in 2008 to 0.11 percentage points in 2009. For the past 5 years, the contribution of this set of capital has turned negative. This is a matter of concern, since R&D capital has formerly been an important source of economic growth. Combined with the deterioration of other capital sets, this evokes the vital question of how this development can be reversed.

[10] See the whole data in the Annex.

The reduction in other capital assets is not as alarming, because their contribution to value added has been relatively small through the whole observation period. Moreover, the assets such as machinery and equipment or non-residential buildings might be affected by overall production trends. As it has been mentioned earlier, at the beginning of 21^{st} century, the firms have changed their investment patterns away from traditional fixed assets such as machinery and equipment towards capital of higher productivity. The investments in R&D capital and overall technological development have changed the structures of factors needed in production. The new methods provided by research and development combined with effects of MFP have made it possible to create more valuable output in more efficient ways. Furthermore, the structural changes in economy such as the importance of some industries for the total value added have been undergoing changes, which affect the investment patterns. For example, such structural changes can be the growing share of service industries compared with the earlier time (before 1995) when manufacturing had been the most dominant cluster of industries. Conjointly, arising importance of high-tech manufacturing industries in the past years and the worldwide changes in the demand of goods produced by manufacturing (the shift from stiff machinery towards "smart" high-tech devices), have affected the needs for different asset types.

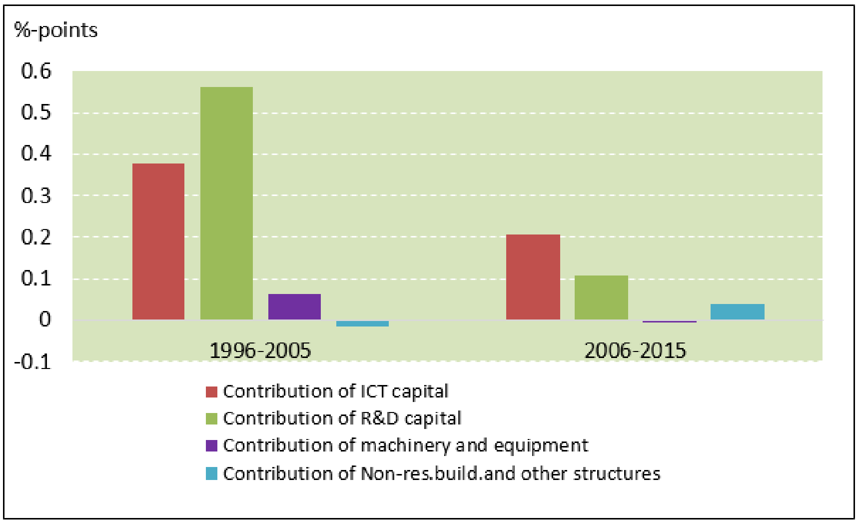

Figure 5
Average contributions of capital services to value added.

4.2 Contributions to aggregate labour productivity

In this section, the development of labour productivity and its subcomponents is examined. The section covers the analysis at the whole economy level. The time period follows the duration of value added analysis, 1996-2015. In the same manner as earlier, the inspection period is divided into two sections of 1996-2005 and 2006-2015. The examination considers the economy level analysis and deepens into causes of labour productivity slowdown. The disaggregation of capital brings an additional twist to the study. This section focuses on finding the factors that have had the greatest effect on the growth of labour productivity. I am keen on gathering valuable information on how the particular sets of capital have influenced the growth of labour productivity and whether there been unexpected changes, which have slowed down the evolution of labour productivity.

The Table 2 presents the average annual growth rates of labour productivity and the average contributions of factors that affect the labour productivity during the periods of 1996-2005 and 2006-2015. Consistent with the theory, the aggregated labour productivity at the whole economy level consists of capital deepening, labour composition term, multifactor-productivity and labour reallocation term. Capital deepening measures the amount of capital that can be used per one hour worked. In the ideal situation, by increasing the capital deepening more value can be produced in one hour and consequently this would increase the labour productivity.

The aggregated labour productivity in Table 2 is a weighted measure of labour productivities of all industries. The sum of this measure and the effect of labour reallocation term equals the total labour productivity of the Finnish economy (see eq. (18)). Labour reallocation term measures the reallocation of worked hours. The term is positive and accelerates the growth of total labour productivity in the economy, when the industries with relatively high value added experience a faster growth in hours worked. If the term is negative, this indicates that working hours have been reallocated inefficiently toward industries that produce lower output in terms of value added.

The labour productivity aggregated from industry level can be further decomposed into contributions of capital intensity, labour composition and MFP. The remarkable contribution of this study is the decomposed capital input (decomposed total capital deepening). Separate contributions of each capital set can be seen in Table 2. The values are logarithmic %-points.

Table 2
The factor contributions to the labour productivity growth of the Finnish non-residential market sector.

	1996-2005	2006-2015	diff.
Contribution of total capital intensity	**0.74**	**0.71**	**-0.02**
Contribution of ICT-capitalintensity	0.36	0.24	-0.12
Contribution of R&D intensity	0.44	0.30	-0.13
Contribution of equipment and machinery capitalintensity	0.01	0.07	0.06
Contribution of non-res.building and other structures	-0.06	0.09	0.15
Labour composition contribution	**0.14**	**0.13**	**-0.01**
MFP	**2.56**	**-0.17**	**-2.73**
Labour productivity (aggregated)	3.44	0.68	-2.76
Labour reallocation term	**-0.39**	**-0.52**	**-0.14**
Labour productivity (whole economy)	**3.05**	**0.15**	**-2.90**

Note: the presented estimates are average annual growth/contribution rates of periods 1996-2005 and 2006-2015.
The third column (diff.) represents the differences between the period 2006-2015 and 1996-2005.

In the period of 1996-2015, the greatest component that affected the growth of labour productivity was MFP. Its contribution was as high as 2.56 percentage points, which accounted for almost 75 % of aggregated labour productivity growth. During the same period, the effect of total capital intensity was on the second place in terms of the magnitude of contribution. Its impact on LP was 0.74 %-points, which accounted for approximately 22 % of aggregated average growth of labour productivity.

The contribution of labour composition term was relatively small. It affected the aggregated labour productivity growth only by 4 % on average. The total labour productivity growth resulted in 3.05 after the magnitude of labour reallocation effect has been taken into the account. The negative effect of labour reallocation has been quite significant. In its absolute value the effect of reallocation of hours between industries accounted for almost 13 % of total labour productivity.

The effect of capital deepening, labour composition term and MFP on total labour productivity (the bottom line in Table 2) was 24 %, 5 % and 84%, respectively. Within the total capital input (capital deepening), the R&D capital had the greatest impact with contribution of 0.44 %-points. This accounts for 14 % of total labour productivity growth. Along with R&D capital, the contribution of ICT capital deepening to labour productivity was considerably high 0.36 %-points. This is roughly half of total capital contribution to LP. However, this result is not outstanding, since as it has been discussed in the previous section, the contribution of Nokia and rapid development of “wireless” economy had boosted the exploitation of R&D and ICT capital with higher productivity abilities, which paced the labour productivity. In the former period, the economy had benefited immensely from the new possibilities that the ICT-boom brought with it. Incorporating computers into the daily production, as well as the acquisition of new technical equipment had boosted the labour productivity.

The aggregated labour productivity has most certainly also been affected by the growth of LP in new industries such as “Telecommunications”, “Information service activities”, “Computer programming, consultancy and related activities”, “Manufacture of computer” and “Manufacture of electrical equipment, electronic and optical products”. The production of some industries has benefited highly from the investments in R&D and ICT capital as their production process can be affected by the brisk development of e.g. high quality ICT equipment, such as the “Manufacture of basic pharmaceutical products and pharmaceutical preparations”, which consumes high-tech equipment and this has had a positive influence on the labour productivity of the industry in question. When this industry achieved a higher value added, its share of total value added in the economy increased and the impact of this industry on aggregated labor productivity had also become more significant.

The second period reveals an entirely different picture. Whereas in the first period the total labour productivity was 3.05 %, in the period 2006-2015 it had dropped to the meager level of 0.15 %. This clear decline is for a severe part caused by abrupt change in MFP. The average annual growth of total labour productivity in economy of Finland in 2015 was even lower, being 0.08.

Over the period of 2006-2015, the highest, positive, contribution to growth of labour productivity belongs to total capital intensity. Within this component, the ICT and R&D capital have affected the growth the most. The average annual contribution of ICT capital was 0.24 %-points and for R&D capital 0.30 %-points. The total contribution of capital to growth of LP was quite surprisingly on virtually the same level as in the previous period 1996-2005.

Whereas the capital had distinctly lost the ability to increase value added, the similar changes cannot be seen in capital intensity, i.e. there is no loss in contribution of capital to labour productivity. This suggests that in both periods 1996-2005 and 2006-2015 the amount of capital used per hour worked has maintained its productivity.

The contribution of labour composition term has not shown signs of deviation from the level in the prior period, which implicates that there have not been any significant negative or positive changes in the structure of the labour force. Roughly said, labor force consists of workers, who belong to similar labour type characteristics (education level, age group, gender) and this composition has not changed between these two inspection periods. For example, the data indicate that there have not been significant shifts inside the economy towards occupations demanding less-skilled labour force. If this is true, the relative share of workers with e.g. lower skill level, who, in theory, have lower income would increase and this would diminish the labour composition term.

However, it must be noted that figures in the Table 2 are annual averages of longer time periods and thus the results are tied to the concept. The effect of labour reallocation has, in turn, become more negative. In real terms, this result suggests that more working hours have been done in such industries that produce less value added. The effect of labour re-allocation has been quite notable, since before taking into account the effect of re-allocation of hours, the average labour productivity growth aggregated from industry level was 0.68 (log)%.

In the following Figure 6, the annual contributions from total capital intensity and its components are presented. These data express a few interesting observations. There are two “spike”-periods in the given total observation period. All of the capital intensity sets experienced some growth in the period of 1999-2003. The most extensive growth can be seen in contributions of ICT and R&D capital. Contribution of R&D capital had been on an exceptionally high level at the beginning of the 21st century. The effect of this capital set contributed the most on the overall effect of total capital intensity from 1999 to 2003. In the latest years, the contribution of R&D capital has almost evaporated, which is a great matter of concern since formerly this set of capital has had a significant influence on labour productivity growth.

After a slight increase in contribution of ICT capital deepening in 1995, this series has maintained a steady annual contribution rate, except for the last 5 years of the inspection period. Although the data shows a modest increase in the contribution of total capital intensity in the latest years of the time series, the overall level is nearly three times lower than for example in 2002 (1.5 %-points). In the past three years ICT capital deepening has had an important role in sustaining the total capital intensity on a positive level.

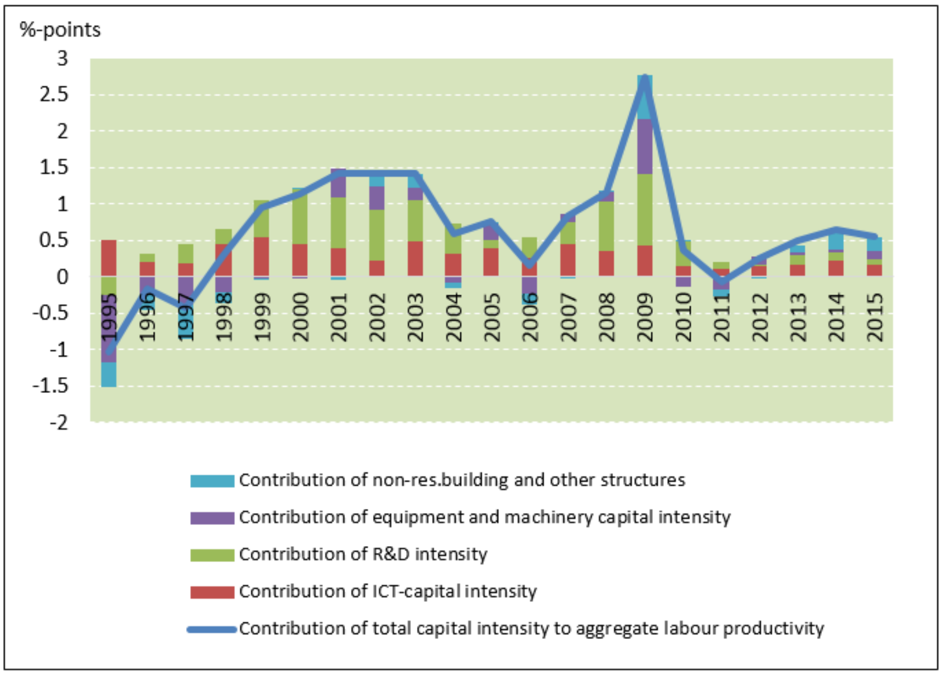

Figure 6
Annual contributions of total capital intensity and its components to aggregate labour productivity.

4.3 Summary of the economy level analysis

The section 4.3 summarizes the analysis of economic and productivity development on aggregate economy level. The results presented in the subchapters above follow the methodological approach presented in chapter 2. The growth accounting approach reveals important information about the factors that affected the economic growth and labour productivity in Finland. However, due to limitations of this model, any strict causal interpretations cannot be directly established. Nonetheless, the growth accounting model enables the disaggregation of labour and capital inputs and provides a valuable insight into each subcomponent of primary inputs. The objective of this study was to disaggregate the capital input and inspect the contributions of each capital asset group to detect possible fluctuations that have decelerated the economic growth and development of labour productivity. This has been achieved successfully.

The results show that the greatest cause of the slowdown in economic growth is due to collapse of multifactor-productivity. During the period 1996-2005, the MFP was the prime factor of creating value and its contribution was approximately two times higher than the contribution of labour input and almost three times as high as the contribution of capital input. All factors were affected by the financial crisis in 2008, but in the latter period 2006-2015 the contribution of MFP has diminished. The exhaustion of MFP is a cause for concern, since, conceptually MFP represents the ability to produce more (or more valuable output) from the same amount of scarce inputs.

According to neoclassical theory, growth in MFP represents a shift towards higher production function and, thus, higher living standards. The MFP captures the new ideas and possibilities that encourage new investments or opening new businesses or hiring more labour. Through this channel, the slump in MFP affects the investment activity and could, consequently, stagnate the economic growth even further.

A great fall is also seen in the contribution of R&D capital. In the past few years, this contribution has turned negative. Contribution from ICT capital to aggregate value added has decreased, but remained positive. The contribution of total labour input had dropped, which was the cause of negative contribution of hours worked. Labour composition was scarcely positive and remained unchanged in comparison of 1996-2005 and 2006-2015.

The results on labour productivity display virtually the same picture as the result on economic growth and MFP. A significant drop is seen in labour productivity in the period 2006-2015. The decline in industry level aggregated labour productivity is -80 % and the decline in total labour productivity (that is including the labour reallocation term) approaches -95 %.

The contribution of total capital intensity has not shown signs of decreasing in the past decade. Disaggregation of capital intensity reveals that ICT and R&D capital have maintained their position as the most influential capital types, although they have experienced on average a 0.13 %-point decline. Other capital types have improved their contributions to labour productivity, but their significance remained relatively minor in the long-run inspection.

Contribution of labour composition has remained stable. The greatest fall is seen in MFP and it appears to be the greatest factor that affected the stagnation of labour productivity. The labour reallocation term has had a significant negative effect on aggregated labour productivity, which led to even lower average level of total labour productivity in the Finnish economy in the period 2006-2015. This indicates that labour has been reallocated inefficiently towards industries with lower value producing abilities.

The comparison of the two periods implies that on average the capital has been used efficiently, since the contributions of total capital intensity and the subgroups of capital have been mostly positive. This leads to the conclusion that there is no need to simply invest more. However, the disaggregating the capital intensity reveals somewhat different needs. The contributions of ICT and R&D capital intensities have declined. The trends of R&D capital contributions indicate that there is a necessity to invest correctly. This includes the stimulating innovative activities and R&D investments.

5. Structural changes in the economy

The chapter 5 analysis the structural changes in the economy. By structural changes the alternated importance of some industries or e.g. the shifts in value production from manufacturing towards service industries are meant. Chapter 5 is divided in five parts. Each subchapter investigates a particular area of interest. The goals are to reveal the structural changes that have occurred in the economy between the first period 1996-2005 and the second period 2006-2015. The analysis considers such issues as, which industries were responsible for high economic growth and the phenomenal development of labour productivity in the first observation period 1996-2005. Further, the discussion considers the latter period of 2006-2015 and exposes the main changes in industry structures, which are responsible for the depression of growth in labour productivity, stagnation of MFP and decrease in value added.

Firstly, the results on contributions from industries to value added are presented (section 5.1). As was shown previously, the MFP plays a great role in economic growth and the development of labour productivity. In the past decade, the multifactor-productivity has had a decreasing trend. Thus, it seems reasonable to study which industries are behind this development (section 5.2). The R&D capital has had a significant effect on value added. Despite this study doesn't interfere with the discussion about the connection between multifactor-productivity and R&D capital, it is still useful to investigate the structural changes behind the R&D capital set. Section 5.3 focuses on this matter. The summary of the results concludes the chapter 5.

The industries are divided following the guidelines of Eurostat manual on aggregating industries into "High-tech industry"-division and the industries of "Knowledge – intensive services". The guidelines provide an exact classification according to which the manufacturing industries can be allocated to "high-technology", "medium high-technology", "medium low-technology" and "low-technology industries". Service industries are mainly aggregated into "knowledge-intensive services" (KIS). Statistics on "high-tech industry" and "knowledge-intensive services" comprise economic growth and labour productivity development by breaking down manufacturing and services industries by technological intensity.

The industry classification of Eurostat is based on Statistical classification of economic activities in the European Community (NACE) at 2-digit level. In this approach, the classification of industry depends on its technological intensity. According to Eurostat, the technological intensity is defined as R&D expenditure/value added. However, the "high-technology" (HT), "medium high-technology" (MHT), "medium low-technology" and "low-technology industries" classification is done only for manufacturing industries. Services are aggregated into knowledge-intensive services (KIS) based on the share of tertiary educated persons at NACE 2-digit level. NACE 2-digit level corresponds to the industry classification of Statistics Finland. When this classification is used, it is justified to assume, for example, that industry such as "Manufacture of computer, electronic and optical products" (Industry classification code 26) has high R&D expenditure and is also a great consumer of high-tech ICT equipment and other advanced technology.

5.1 Contributions of industries to aggregate value added

This section presents the contributions from industries to aggregate value added. As has been determined earlier, the economic growth in terms of value added has been depressed since the crisis in 2008. The Table 3 depicts the main industries that have boosted the growth in the period before the crisis and provides an insight into, which industries have suffered the most. Thus, it can be determined to which industries the post-crisis stagnation of economic growth can be attributed.

Table 3
Contributions of industries to aggregate value added.

	1996-2005	2006-2015	diff.
Total value added	**4.76**	**0.14**	**-4.62**
High-technology + medium high-technology industries	**1.77**	**-0.04**	**-1.81**
High-technology industries	**1.51**	**-0.08**	**-1.60**
Manufacture of basic pharmaceutical products and pharmaceutical preparations	0.03	0.07	0.04
Manufacture of computer, electronic and optical products	1.48	-0.15	-1.63
Medium high-technology industries	**0.25**	**0.04**	**-0.21**
Manufacture of chemicals and chemical products	0.04	0.02	-0.02
Manufacture of electrical equipment	0.08	0.03	-0.05
Manufacture of machinery and equipment n.e.c.	0.13	0.02	-0.10
Manufacture of motor vehicles, trailers and semi-trailers	0.03	0.00	-0.03
Manufacture of other transport equipment	-0.01	-0.03	-0.02
Medium low-technology	**0.34**	**-0.20**	**-0.54**
Low-technology industries	**0.28**	**-0.19**	**-0.48**
KIS industries	**1.05**	**0.48**	**-0.58**
Other industries	**1.32**	**0.10**	**-1.22**

Note: the presented estimates are average contributions of industries in periods 1996-2005 and 2006-2015.
The third column (diff.) represents the differences between the period 2006-2015 and 1996-2005.
Values presented are logarithmic percentage points.

The upper line of Table 3 presents the average logarithmic growth rates of value added for total economy level. Each line below shows the contribution of given industry cluster. In the period of 1996-2005, the most important industries for overall economic growth in terms of value added have been the "high-technology", "medium high-technology", "knowledge-intensive services" and the cluster of the rest of the industries ("Other industries"). A plausible explanation behind this development is that the rising demands of "wireless" economy boosted the production in "HT+MHT" industries but there were also massive positive spillovers of this strong development. The spillovers can be seen as increased production in "Other industries" and increased demand of "knowledge-intensive services" can be detected in contribution of KIS industries.

A more drastic picture is provided by the latter period. The contributions of all high-tech industry clusters have dropped close to zero or turned negative. According to these results, the value added remained positive only due to the positive contribution of KIS industries. A small positive contribution can be also seen for "Other industries". The most dramatic fall is experienced by "Manufacture of computer, electronic and optical products" industry, which was responsible for 1.48 %-points of total growth of value added. In the period 2006-2015, the average contribution of this industry to value added was -0.15 %-points.

The dreadful performance of high-technology industries could be partly explained by a decrease of export of high-tech equipment and theme related products. The reasons behind the decrease in exports could be that the worldwide demand for such products is depressed or Finnish high-tech manufacturing cannot respond to the demands of audience. The case can also be that supply provided by Finnish high-tech industries does not fully meet the international demand, which would imply a partial mismatch between the produced goods and the goods that are wanted on the markets. For example, Finland can fail to produce the demanded product fully or can provide only some parts of the production, which leads to a situation where buying party purchases this product fully or partly elsewhere. However, the growing positive contribution of KIS industries must not be ignored. It is logical to assume that the KIS industries will strengthen their position in economic structure and in the future the contribution could increase further on via production of high-quality and valuable services.

5.2 Contributions of industries to aggregate MFP

This following subchapter studies the contributions of various industry groups on multifactor-productivity of whole economy level. As has been noted earlier, the MFP has a significant impact on the development of both the economic growth and the labour productivity; and as we know from previous results, the development of MFP has been undesirable. This section is particularly important, since it reveals the main structural changes in the economy that have affected the productivity development in the past decades. Considering the importance of MFP, this section offers invaluable answers to such questions as "What are the industries responsible for productivity growth?", "Which industries have affected the total productivity development the most?" and "Have there been re-allocations between the industries in terms of MFP?".

Few points must be highlighted before further analysis. Firstly, this section examines the contributions of industries to aggregate level of MFP, not the contributions of MFP on industry level. Secondly, as was mentioned earlier, the MFP — as presented by Jorgenson *et al.* (2005) and supplemented by Oulton (2016) — reflects additional factors and not just the pure technological change. The MFP can include changes in utilization of inputs, resource reallocations, economy of scale and a measurement error. To be clear, there is no unambiguous way of interpreting the negative contribution of MFP. The negative measure of this factor does state the worsening productive efficiency, but the reasons behind this phenomena can be diverse. Jorgenson *et al.* (2005) suggests that it is due to e.g. barriers of entry to the markets or to increased rigidity in allocative forces (e.g. market regulations). Oulton (2016) proposes that transitory negative MFP contribution can occur due to incomplete re-allocation of resources (which will eventually result in higher productivity but in the measurement moment the observed effect is negative) or due to a measurement error, which is included to MFP residual. The negative measure of MFP could also imply a decline in research productivity and the loss of idea creating ability (Jones, Van Reenen, and Webb 2017).

Table 4
Contributions of industries to aggregate MFP

	1996-2005	2006-2015	diff.
Total MFP	**2.56**	**-0.17**	**-2.73**
High-technology + medium high-technology industries	**0.90**	**-0.05**	**-0.95**
High-technology industries	**0.72**	**-0.03**	**-0.75**
Manufacture of basic pharmaceutical products and pharmaceutical preparations	**0.02**	**0.05**	**0.03**
Manufacture of computer, electronic and optical products	0.69	-0.09	-0.78
Medium high-technology industries	0.18	-0.01	-0.20
Manufacture of chemicals and chemical products	**0.03**	**0.03**	**0.00**
Manufacture of electrical equipment	0.06	0.00	-0.07
Manufacture of machinery and equipment n.e.c.	0.06	-0.03	-0.10
Manufacture of motor vehicles, trailers and semi-trailers	0.02	0.01	-0.01
Manufacture of other transport equipment	0.00	-0.02	-0.02
Medium low-technology	0.14	-0.15	-0.29
Low-technology industries	**0.35**	**0.04**	**-0.32**
KIS industries	**0.53**	**0.08**	**-0.45**
Other industries	**0.64**	**-0.09**	**-0.73**

Note: the presented estimates are average contributions of industries in periods 1996-2005 and 2006-2015.
The third column (diff.) represents the differences between the period 2006-2015 and 1996-2005.
Values presented are logarithmic percentage points.

The Table 4 displays the annual average contributions of each industry cluster to aggregate MFP. The figures represent the contributions of each individual industry (e.g. "Manufacture of computer, electronic and optical products") or industry clusters (such as High-technology industries) to aggregate economy level of multifactor-productivity. If a significant collapse is seen in one of the most important industry clusters, this effect is definitely seen at the level of whole economy as well. Note that the aggregate level of MFP for each period 1996-2005 and 2006-2015 is the same average value as presented previously in Table 1 (in section 4.1 Contribution to aggregate value added).

The aggregate average MFP growth in the period 1996-2005 was 2.56 logarithmic %-points. This consisted for the most part of contributions from "high-technology" manufacturing industries. The highest contribution of all can be traced to one single industry – "Manufacture of computer, electronic and optical products". This result is highly meaningful, since it can be said that one industry accounted for approximately 30 % of total innovative and technological growth. Not to underestimate the result, but this is hardly surprising considering the overall economic situation of the period 1996-2005 and the effect of Nokia and which industry was primarily responsible for producing value and boosting the economy.

To some degree, a surprising result is that the total contribution of "medium-high-tech" industries was relatively small and that the contribution of each individual industry in this class was also minor. If one does not take into account the contribution of the mixed category of "Other industries", the KIS industries rank second in terms of magnitude of contribution to aggregate MFP. However, this result was anticipated, since KIS industries provide services related to high-tech technologies or are active users of ICT and high-tech equipment. If one of the industries in this pair experiences a growth, a similar development might be seen also in the other industry. This result is particularly strengthened by results from the period 1996-2005. When the high-tech and medium high-tech industries experienced a massive growth, the positive spillover effects can also be seen for the KIS industries.

The column 3, which presents the differences between the periods 1996-2005 and 2006-2015, reflects well the negative changes of MFP in the economy. It portrays the sharp decline in MFP that high-tech and medium high-tech industries experienced. Despite a quite significant decline in MFP of KIS industries, their contribution to aggregate level of MFP remained slightly positive. It can be easily seen from Table 4 the collapse of which industries has caused the downturn of whole economy level MFP.

5.3 Structural change in aggregate R&D capital

As the data have revealed on several occasions, the total contribution of capital services has decreased and the biggest decline is seen in contribution of R&D. Since this set of capital has an important role of creating more valuable output, it is in the best interest of this study to investigate in detail the structural change behind the aggregate R&D capital. This chapter explores, which industries have been the most important investors in R&D activity and which industries can be held responsible for the decline in contributions from this set of capital.

The R&D capital plays an important role in enhancing the production process. It also makes the output more desirable and, along these lines, more valuable. The successful application of R&D can create new methods of production or create new goods. The contribution of R&D can be transmitted through two channels. On one hand, due to R&D, new products can be created or some significant improvements can be introduced to already exciting products or services. The effects through this channel can be detected in higher prices and in specific demand for such products. As an example, such a product could be a new vaccine in the field of medicine or a new high-tech equipment for executing challenging surgeries. A new medicine could be costly at first and has a specific market, but the profits of the inventor will have higher value.

On the other hand, due to increased R&D activity new production methods can be identified. This leads to higher efficiency and lower costs. In the longer run, the more efficient production would affect prices negatively and thus the prices would go down. However, this does not imply that the product would be different or lose its efficiency. A simple example of this is an assembly line. This mass production technique was developed and implemented into the production of automobiles in the early 1900´s in H. Ford´s manufacturing plants enabled efficient and sequential production. The efficiency of automobiles remained the same but lowered prices made the output affordable to a larger audience.

Another, more recent example, is the spreading and the implementation of computers and telecommunication devices. At first, computers were expensive and available only for a specific market, but as development continued, production became more efficient and prices fell significantly leading to a higher demand. Computers became an essential element of everyday life and production of goods and services. Nevertheless, the efficiency of computers did not decrease, on the contrary, computers became even more powerful. Due to successful investments in R&D, economies can boost the value creation and increase labour productivity as in the case with the .com-boom.

The Figure 7 displays the trend developments of contributions from R&D capital to value added (red line) and to labour productivity (blue line). The trendlines are formed using Hodrick–Prescott filter and are based on annual contributions. The HP-filter (also known as Hodrick–Prescott decomposition) is a mathematical tool used in macroeconomics to obtain a smoothed-curve representation of a time series. It is especially useful in real business cycle theory, to remove the cyclical component of a time series from raw data. The HP-filtered series are more sensitive to long-term than to short-term fluctuations. The adjustment of the sensitivity of the trend to short-term fluctuations is achieved by modifying a multiplier lambda (λ). Here the λ is set to be 6.25 as it is a recommendation for series, which handle the annual changes rates.

The annual data reveal that the contributions of R&D capital have been close to zero or turned negative since 2010. This negative development considers the contributions to value added. The contribution of R&D intensity (the R&D capital per hour worked) has remained slightly positive even after the 2008 crisis, but a significant decline is seen also in these series.

Both of the HP filtered trendlines have a clear decreasing trend in the past 15 years. However, as the components of labour productivity are bound to changes in total (unweighted) hours worked, all of the measures are affected by great anomalies in changes of hours worked as, for example, when in 2009 the Finnish economy faced a major wave of layoffs and experienced a steep decline in total hours worked. The situation can be understood as such an anomaly occurs when the changes in hours worked exceed the changes in contributions of, for example, R&D capital and thus the contribution of R&D capital intensity can transitorily experience an increase (i.e. due to abnormal development, there is more of R&D capital per one hour worked). However, in the consequent period measures will adjust to the conditions.

The measures that affect value added and the labour productivity are, nonetheless, inseparable. If the decline in R&D activity is detected in analysis of value added, it will also show in the labour productivity measures. Therefore, to inspect the pure effect of R&D activity on value added, in this section, I have chosen to focus on the average annual contributions from R&D capital to value added. The analysis of the sequential paragraphs is done with the regard to industries, which have affected the development of R&D activity the most.

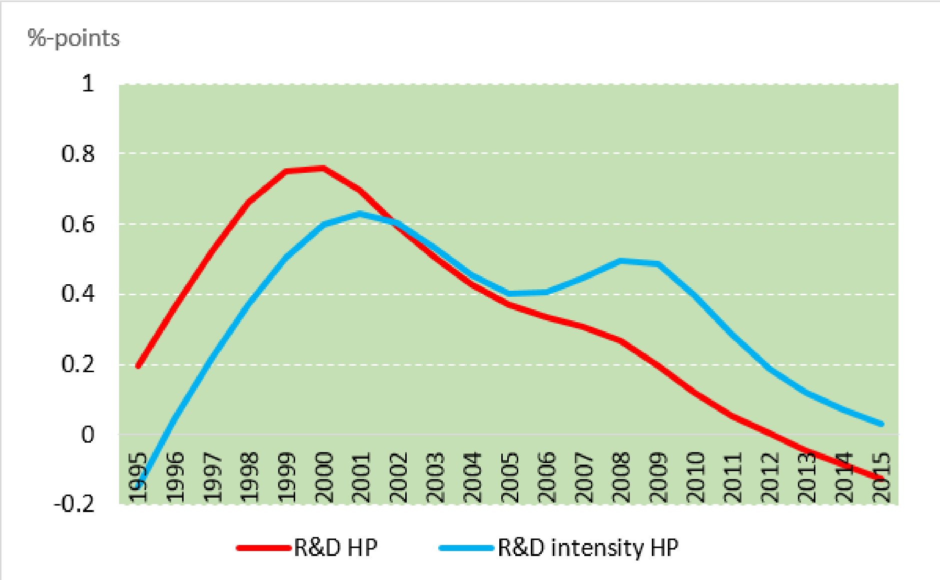

Figure 7
Trends of contributions of R&D capital to value added and labour productivity.

The Table 5 presents the structural changes in the Finnish non-residential market sector. The estimates presented are average annual contribution rates of a given time period. The table should be interpreted as how strongly has each particular industry or industry cluster affected the aggregate level of R&D contribution to aggregate value added. Note that the aggregate level of R&D here (Table 5) is the same as the contributions of R&D capital to aggregate value added at the whole economy level presented in section 4.1 Table 1.

Table 5
Contribution of industries to aggregate R&D level

	1996-2005	2006-2015	diff.
Total (aggregated) R&D level	**0.56**	**0.11**	**-0.45**
High-technology + medium high-technology industries	**0.50**	**0.10**	**-0.40**
High-technology industries	**0.48**	**0.06**	**-0.43**
Manufacture of basic pharmaceutical products and pharmaceutical preparations	0.01	0.01	0.00
Manufacture of computer, electronic and optical products	0.48	0.05	-0.43
Medium high-technology industries	**0.02**	**0.05**	**0.03**
Medium low-technology	**0.01**	**-0.01**	**-0.02**
Low-technology industries	**0.01**	**-0.01**	**-0.02**
KIS industries	**0.04**	**0.02**	**-0.01**
Other industries	**0.00**	**0.00**	**0.00**

Note: the presented estimates are average contribution rates of periods 1996-2005 and 2006-2015.
The third column (diff.) represents the differences between the period 2006-2015 and 1996-2005.
Values presented are logarithmic percentage points.

The Table 5 makes a strong statement about the development and structure of R&D activity in Finland. Firstly, a great difference is seen between aggregate contribution rates of the two periods in question. The average annual contribution of the first period 1996-2005 was 0.56 percentage points. The contribution seen in the following period is only 0.11 percentage points. It is easy to see that high-tech industries played a great role in the composition of aggregate R&D activity.

Throughout the late 90s and the early 2000s, the R&D capital had a strong position in creating value. Linking this analysis to the discussion in the previous chapters, it can be stated that the R&D activity has been at the highest in those industries, which were responsible for the exponential development of multifactor-productivity and value added in the first inspection period. The highest contribution to aggregate R&D activity is assigned to one industry – the "Manufacture of computer, electronica and optical products".

In the following period of 2006-2015, the contributions of all industries to aggregate R&D activity have dropped. The steepest decline is seen in the contribution of "Manufacture of computer, electronical and optical products" resulting in the declining contribution of the whole high-tech manufacturing industry cluster. That contribution was 0.10 percentage points in the latter period 2006-2015. However, the Table 5 also reveals that medium high-tech manufacturing industries have even gained their diminutive contribution to R&D activity and the industry of "Manufacture of pharmaceutical products and pharmaceutical preparations" has not undergone any changes.

The presented values are annual averages. Needless to say, if the development of each industry is inspected separately, some significant annual changes could be seen for a given industry j. Regardless, the Table 5 supports the results of the previous chapters (e.g. the Figure 3 and 4). The Finnish economy has experienced a decline in R&D investments, which is a concerning matter since other, conventional, capital asset types have not been as productive (excluding ICT capital) and do not generate positive externalities as the R&D capital does.

5.4 Structural change in aggregate labour productivity

This section discusses the contribution of industries to aggregate labour productivity. The objective of this analysis is to determine the structural changes within the industry composition that have occurred in the Finnish economy during the past decades. This analysis allows us to find out which industries have maintained the growth of labour productivity in Finland and to diagnose, which industries have slowed the growth in aggregated labour productivity.

The main results are presented in Table 6. The presented values are average annual contributions of each industry to aggregate labour productivity. The table is divided into two time periods and the last column demonstrates the difference between the two periods in question. Values are logarithmic percentage points. The subvalues sum up to the aggregate level. For example, the effect of industry "Manufacture of computer, electronic and optical products" to aggregate labour productivity was 0.48 percentage points. This sums up to contribution of "high technology industries", which in own turn, sums up to the upper level.

Counted from the data for whole period of 1996-2015, the contribution of "Manufacture of computer, electronic and optical products" to aggregate labour productivity was 1.23 %-points. This contribution forms approximately 36 % of the total labour productivity growth during this period. As a reminder and to put results into a larger perspective, it must be noted that this study includes altogether 54 industries.

The class "high-technology" includes 2 industries, "medium high-technology" includes 5 industries, "medium low-technology" includes 6 and "low-technology industries" class has 6 industries. The "knowledge-intensive services" class includes the majority of 18 industries and the class "other industries" has 17 industries. In the period 1996-2005, as it was the golden time of the Finnish economy, all of the classes had, on average, positive contributions. However, the data reveals that the class of "high-technology" industries had the greatest impact. Combined together with "medium high-technology" industries this accounted for roughly 50 % of total labour productivity growth. To put it in another way, the growth in labour productivity during the period of 1996-2005 can be mostly attributed to growth of labour productivity of 7 industries.

When comparing the two periods 1996-2005 and 2006-2015, a 77 % decline can be seen in contribution of "HT+MHT" class. Although a similar decline can be seen in the contribution of KIS industries, the magnitude of the latter drop is somewhat lower, -54 %. Yet, the annual contribution of KIS industries in 2015 shows a significant improvement over the annual average. The contribution is 0.34 %-points and it is 0.09 percentage points higher that the annual average of 2006-2015. A closer investigation reveals that while the contribution of "HT+MHT" industry class has experienced a major decline in the past two years, the contribution of KIS industries has maintained a relatively high level.

The results in Table 6 imply that the main factors behind the labour productivity slowdown are due to lowered contribution of mainly high-tech industries. The overall stagnation (period 2006-2015) of the Finnish economy is detected also in the contribution of the "Other industries" class. Nonetheless, when considering the relative sizes of “HT+MHT” and “Other industries” (the former contains 7 and the latter 17 industries), the decrease of labour productivity is distributed on a larger amount of industries than in the former class. Thus, the growth stimulating measures must be directed, above all, to “HT+MHT” manufacturing industries. The KIS industries must not be ignored either.

Table 6
Contributions of industries to aggregated labour productivity.

	1996-2005	2006-2015	diff.
Total (aggregated) labour productivity	**3.44**	**0.68**	**-2.76**
High-technology + medium high-technology industries	**1.50**	**0.35**	**-1.14**
High-technology industries	**1.26**	**0.27**	**-0.99**
Manufacture of basic pharmaceutical products and pharmaceutical preparations	0.03	0.06	0.04
Manufacture of computer, electronic and optical products	1.23	0.21	-1.03
Medium high-technology industries	**0.24**	**0.08**	**-0.15**
Manufacture of chemicals and chemical products	0.05	0.05	-0.01
Manufacture of electrical equipment	0.08	0.02	-0.06
Manufacture of machinery and equipment n.e.c.	0.08	0.02	-0.06
Manufacture of motor vehicles, trailers and semi-trailers	0.02	0.01	-0.01
Manufacture of other transport equipment	0.00	-0.02	-0.02
Medium low-technology	**0.22**	**-0.09**	**-0.31**
Low-technology industries	**0.50**	**0.07**	**-0.43**
KIS industries	**0.54**	**0.25**	**-0.29**
Other industries	**0.69**	**0.10**	**-0.59**

Note: the presented estimates are average contributions of industries in periods 1996-2005 and 2006-2015.
The third column (diff.) represents the differences between the period 2006-2015 and 1996-2005.
Values presented are logarithmic percentage points.

5.5 Summary of the results on contributions of industries

The sections 5.1, 5.2, 5.3 and 5.4 discussed the results on structural changes in the economy of Finland during the period of 1995-2015. Each subsection inspected a particular component of productivity analysis. Subchapters 5.1, 5.2 and 5.4 focused on main components: economic growth in terms of value added, multifactor-productivity and labour productivity; whereas the focus of section 5.3 was on structural change of the economy with respect to R&D capital. This subsection summarizes the results on structural change in the economy of Finland.

The data revealed that the exceptionally strong growth of the Finnish economy in the period 1996-2005 is assigned to the strong development of “high-tech” and “medium high-tech” industries. The boosting growth of value added and labour productivity is linked to the growth of multifactor-productivity. The positive externalities arising from the growth of MFP in high-tech industries were also detected in other industries of the economy.

Almost 40 % of growth of value added can be attributed to “high-tech” and “medium high-tech” industries. In the second place comes the cluster of “Other industries” with a share of almost 30%. In the third place in terms of magnitude of contribution to value added growth comes the cluster of knowledge-intensive service industries. The share of KIS industries is responsible for 22 % of the growth. The percentage difference of average annual growth of value added between the first and the last period was -97 %. During the latter period, the contributions of most high-tech industries have turned negative. The industries that maintained a positive growth are knowledge-intensive services.

Similar results were achieved in the analysis of structural change in aggregate labour productivity. The industries that affected the labour productivity the most in the first inspection period were “high-tech” and “medium high-tech industries”. These industries were responsible for 44 % of the growth of labour productivity. The average labour productivity growth in the first period was 3.44 %-points, but dropped to an average of 0.68 %-points during the next period 2006-2015. The slow labour productivity growth is almost entirely assigned to the sharp decline in labour productivity of industries that previously were initiators of the growth.

6. Discussion

Chapter 6 discusses the results of this study. The discussion part presents the newest trends in productivity studies and deliberates about can be done in order to turn the productivity back on growth track. Firstly the result on aggregate economy are discussed. The section 6.1 also analyzes the results of this study in the framework of previous studies. Then, results on structural changes are covered in section 6.2.

6.1 Discussion on the results on aggregate economy

This section discusses the results of the chapter 4. The limitations and restrictions of the growth accounting model must be acknowledged. The conclusions drawn from these results are valuable and the disaggregation of capital input has shed new light on the recent development of economic growth and labour productivity in Finland. However, due to limitations of the growth accounting model, any strict causal interpretations cannot be established, i.e. the inter-connections and relations between the events have been discovered but any exact magnitude of increasing/decreasing of one particular factor and its effects on e.g. labour productivity cannot be directly recognized. Nevertheless, the analysis has disclosed the main reasons of stagnation of economic growth and the reasons behind the slowdown in the growth of labour productivity. In the following, the results of this study in more general framework and the possible future trends are discussed.

For reasons such as different timelines, diverging industries included to the study and differing combination of industries[11], the results of this study cannot be fully compared to previous studies. Even if the final magnitude of contributions from components to value added and labour productivity differ, the similar trends are detected for comparable parts.

The importance of MFP to economic development of Finland has been noticed earlier by Pohjola (2011) and, for Europe in general, underlined by van Ark, O´Mahony and Timmer (2008). This study discloses convergent results.

In the period of 1995-2006 the average annual GDP growth in EU15 was 2.3 %. The growth of labour productivity (GDP per hour worked) was 1.5 %. Based on this study, the growth rates for Finland for period 1996-2005 are considerably higher 4.76 % and 3.05 %, respectively. This can be explained by the facts such as, the study by van Ark *et al.* (2008) include a pool of different countries with diverging growth rates, which might lower the total contribution. As Jalava and Pohjola (2008) discover the overall contribution of ICT to GDP growth has been stronger in Finland than even in the U.S in period 1990-2004 being 1.54 %-points. The results presented in this study are supported by the ones of Pohjola (2011) and Pohjola and Jalava (2008); the MFP had a significant contribution to value added from mid-90s to mid-2000s. The positive economic effect arising from firm contribution of Nokia, i.e. high contributions from ICT and R&D- capital and MFP, provide a plausible explanation for higher growth of the Finnish economy than the EU15 average.

The main conclusions driven from Table 1 and Table 2 for first period 1996-2005 are in line with the previous literature. In the beginning of “wireless era” the economic and labour productivity growth was driven by mostly the same components: the ICT and R&D capital and MFP. The trends of substitution towards capital with higher productivity seen in this study can be as well witnessed in the United States (e.g. Jorgenson *et al.* 2008) and European countries (van Ark *et al.* 2008). Finland has benefited greatly from development of new high technology. An addition of this study is the segregation of contribution of R&D capital, which had a particularly high contribution to labour productivity and economic growth up to mid-2000s.

The timeline in most of the studies mentioned here end by the year 2008 or earlier. The studies approximate that the decline of MFP had started at the breakpoint of the millennium. Results provided by this study show that the trend of MFP and labour productivity have continued decreasing. For the

[11] For example in the beginning of 21st century the interest was mostly focused on ICT capital and ICT-manufacturing and ICT-using industries. In this thesis the industry clusters are based on usage of high technology and a great attention is given to R&D capital. The industries included to the study might differ as well.

past 5 years the Finnish economy has been drifting in the conditions of negative MFP and low labour productivity growth. The optimistic expectations of after millennium literature did not materialize and developed countries, including Finland, are failing to turn the productivity back on track.

As the data show (Tables 1 and 2), the importance of MFP cannot be emphasized enough. The negative changes in this factor cause drastic consequences for economic growth and labour productivity. Equivalently, when the MFP increases, the production possibilities improve and a higher production function is reached. When the certain production efficiency is achieved, also more leisure time becomes available. This increases the overall satisfaction in the economy, improves the competitiveness of the economy and makes it more desirable compared to other economies

An increase in multifactor-productivity also gives incentives to consume. The key idea can be put in the following way: without the methods and the ideas for future business, firms would not hire labour and would not invest in capital or ways to increase their efficiencies. Thus, for example, the decline in investments and the contributions of some capital assets might be dependable on

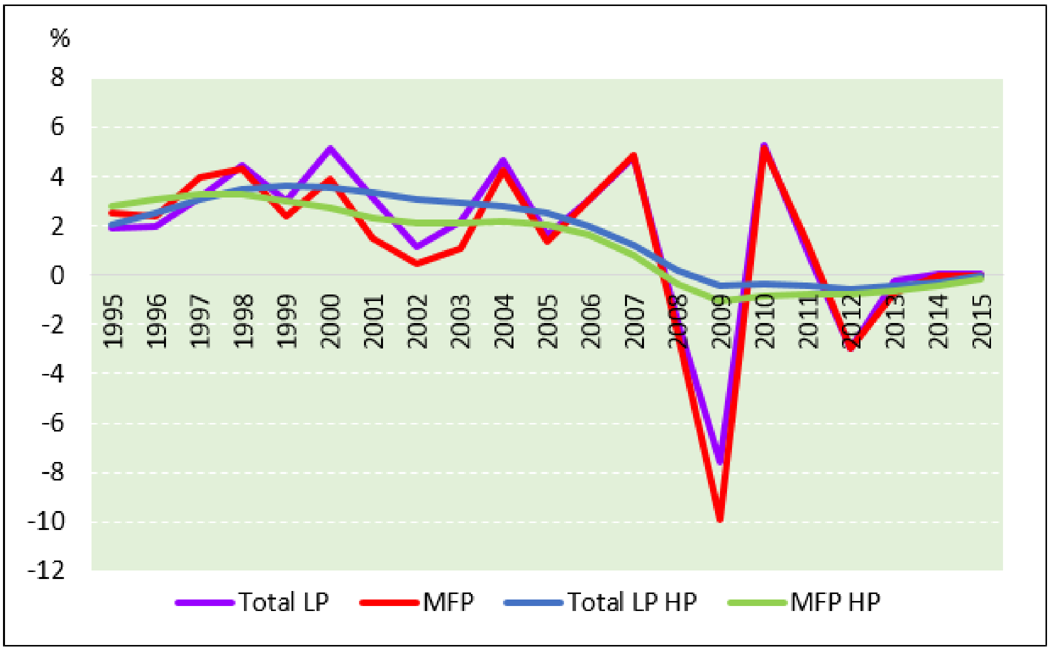

Figure 8
Annual growth of multifactor- and labour productivity and the HP filtered series.

fluctuations in the multifactor-productivity.

Based on the results provided by this particular set of data, the statement about the relation of MFP and investment patterns receives some support. As in the period 1996-2005, the level of MFP was high and the contribution of total capital services was also on a noticeable level. When in the latter period the influence of MFP decreased significantly, the contributions of capital to value added likewise dived. The “close to zero” or negative development of MFP suggests a lack of innovative ideas and loss of capability to make the production more desirable.

The annual growth rates of labour and multifactor-productivities are presented in Figure 8. The smoother lines represent the Hodrick–Prescott filter series. The lambda equals 6.25. The series, which were purified from the cyclical component reveal that both series experienced a smooth decline since 2008.

Another clear picture, which is portrayed by Figure 8, shows the systematic dependency of labour productivity on the multifactor-productivity. Even during the positive spike in 2010 and despite the slightly improved annual development of MFP in the past two years, the course of HP-trends has still been on a downslope and even below zero.

The growth accounting model that is based on legacy of R. Solow assumes that MFP is an exogenous factor. From the point of view of “Solow residual”, not many direct procedures can be applied to change the observed trends in MFP. However, the history of productivity analysis literature has raised skepticism about the exogenous nature of MFP residual. It is quite reasonable to believe that better knowledge accomplished through higher education or thorough work in the field of research and development would contribute positively to creating new methods or generating new ideas.

The latest studies in productivity research have been interested in the relation of R&D capital and MFP (see e.g. Edquist and Henrekson 2015). However, hardly any evidence of strict causality between the expenditure on R&D and its effect on MFP have been recognized. Yet, in the light of the results for the past 10 years, there might be some connection between decrease in contribution of R&D capital and decline in contribution of MFP. When firms invest less in R&D, less fruitful development work is done and the less there are positive spillovers from the R&D activity to other factors. If an approach deviating from “Solow residual” is undertaken, then there might be means to guide MFP back to a positive growth track.

Another interesting finding that contributes to the discussion on the exogeneity of MFP and the relation between the R&D and MFP, is provided by a pioneering paper by Bloom, Jones, Van Reenen and Webb. Their starting point is that the MFP is partly endogenous. They refer to a term “idea TFP”, which is the research productivity of people. They state that the economic growth is for the most part put in motion by the mechanism of creating new ideas.

Bloom *et al.* reconstruct the basic growth accounting model, where the production function is affected by exogenous technological change, in a way that the technological change is assumed to be partly endogenous. They argue that R&D expenditure affect the technological change–more precisely the investments in "human capital" part of R&D expenditure affect the "idea TFP". The part of the R&D expenditure, which is linked to purchasing relevant equipment or renting/constructing laboratories (etc.) is still captured by the capital input in the traditional growth accounting model.

In other words, the authors divide the technological change into two parts and estimate an equation, which retraces the effect of research productivity on the "idea TFP". For the US data, Bloom, Jones, Van Reenen and Webb find that the "idea TFP" falls in half every 13 years–ideas are getting harder and harder to find. They find that the number of researchers required today to achieve the doubling every two years of the density of computer chips is more than 75 times larger than the number required in the early 1970s. To put it in a more common perspective, just to sustain constant growth in GDP per person, the U.S. must double the amount of research effort searching for new ideas every 13 years to offset the increased difficulty of finding new ideas. They emphasize that the "idea TFP" is falling sharply everywhere.

Similar research is needed to get more information on this matter. Based on the results of this thesis, any strict conclusion about this appearance cannot be made, but using the results of Bloom *et al.* some directional thoughts may be formed. The negative development of MFP in the latter period 2006-2015 might be related to this phenomenon. Ideas are harder to find and need more investment in R&D. Simultaneously the pure investment in R&D activity is not sufficient enough since the R&D activity must be productive. At the moment this seems not to be the case as new ideas are getting harder and harder to invent.

The decline in MFP signals the loss of the new ideas and the declined contributions of R&D (see Figure 7, section 5.3) complicates breaking the negative cycle. If the investments in innovative and developing activity are not executed by the private sector in a large enough scale, one possible solution could be the subsidies to firms provided by the public sector. Another proposal could be that the public sector itself would participate more in the enhancement of R&D activity.

The public sector has, nonetheless, an important role in further development, since firms might avoid the vague and unpredictable investments, which, however, would benefit the growth in the long run. From the point of view of a firm some of the investments might seem unprofitable as they are too risky and insecure or the profits from the investment might be unclear in financial terms. The firm withdraws from such an investment. Public financing for such innovative investments would share the risks of introduction and implementation of new technologies. Joint responsibility would provide insurance in case the benefits from new technologies and innovations lag. In this way, the public sector plays an important role in supporting the overall development of labour productivity and economic growth.

6.1.2 Public sector policies and the example of Nokia

The golden time of the Finish economy can be clearly detected in the period 1996-2005. For a great part, the growth of ICT and R&D capital and the value added arising from that can, be attributed to the rise of Nokia. Although, the public sector does not by itself contribute highly to the development of labour productivity and value added, the decisions that stem from this sector are crucial. The importance of political decision-making has been seen once in the early stages of the development of Nokia. As Anil Hira, who has a great expertise in technology policies, states, the result of Nokia occurred due to "a combination of unusual circumstances …, domestic private and public sector cooperation and public procurement policies".

Public sector policies played several times a crucial role in the development of Nokia. For example, public sector´s policies and public companies supported the development of networks by establishing the R&D labs and the Finnish Parliament, on its behalf, doubled the ceiling on foreign ownership to 40% supporting the financing of Nokia in 1987, and after recession in 90´s, the public sector increased support for R&D expenditure. The successful endorsement can be clearly detected even in trend figures (see Figure 7, period of late 90´s and early 00´s). The assistance provided by public policies was competitive and favoured technology clusters (Hira 2012).

The statement of the discussion above strongly implies that together with the correct political decisions, economies can somewhat rapidly create value and improve productivity. In other words, to create value more efficiently or to increase the labour productivity, the right sources of potential development must be recognized and further supported. In the light of recent developments, intervention by the public sector to support innovative activities and encouraging the fulfilment of new ideas and trying new "recipes" could provide a long-needed incensement injection. Even if the private sector carries the potential responsibility for creating higher productivity, the correct and sustainable support from the public sector also contributes to the development in a great manner.

6.2 Discussion on structural changes within the economy

The annual contribution rates reveal that an especially dramatic decline is seen in contribution of "high-technology" industries in the last two years (see Table 5). However, the KIS industries have preserved a relatively high contribution level, which indicates that “knowledge-intensive service industries” have an increasingly important role in the Finnish economy. It is doubtful that influence of high-tech manufacturing industries would disappear entirely in today´s world. After all, the manufacturing sector has always been an important sector in the Finnish economy and producing high-quality technologies and equipment has been a trademark for Finland. Nonetheless, the increasing significance of knowledge-intensive services must not be overlooked.

The evidence of slight increase in KIS industries can be identified in Figure 9, which pictures the index series of annual contributions of each particular industry class. Whereas the contribution of “HT+MHT” class slightly flattens, the KIS industries have marginally increased their share in aggregate labour productivity. The dashed line is the two period moving average for knowledge-intensive services. It depicts well the rise in contributions of KIS industries for the past 5 years.

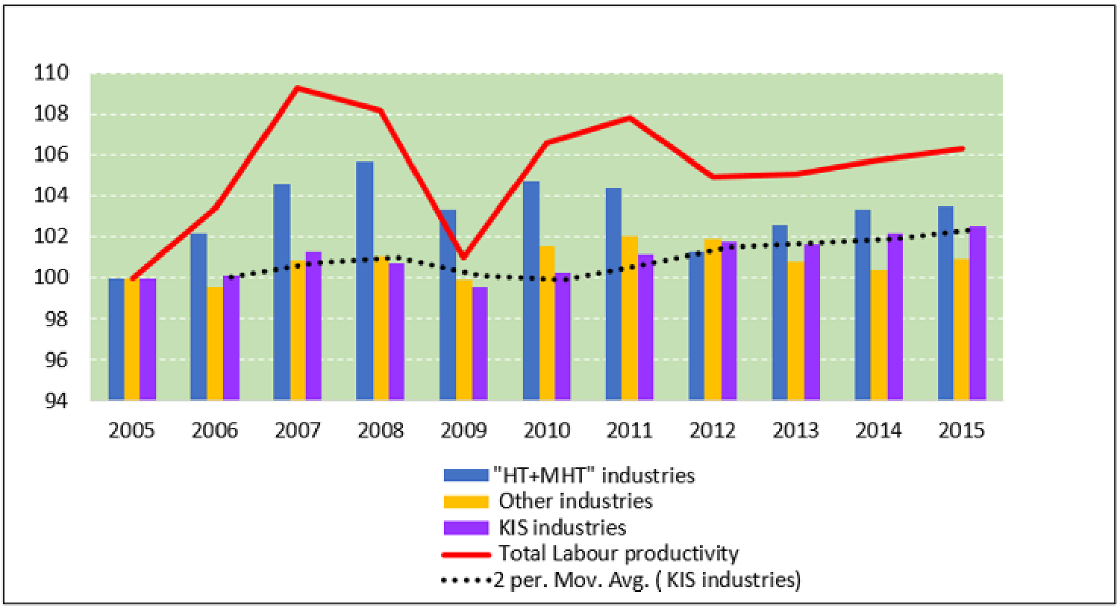

Figure 9
Contributions of industries to aggregated labour productivity, index series (2005=100).

The output of high-tech manufacturing industries has demand in domestic and foreign markets. Such KIS industries as “Telecommunications, computer programming, consultancy and related activities” and “Financial and insurance activities” are important consumers of new technologies and high-tech related services. It might be the case that if the MFP development turns negative in high-tech manufacturing industries, the impact will also be seen in other sectors as the process of creating new technologies slows down. The evolution of contributions of the manufacturing cluster in the latter period can be characterized as manufacturing having, for a great part, lost the productive efficiency and perhaps the means and ideas that stimulate the MFP and economic growth (e.g. see Table 4). The results suggest that the resources in industries with negative multifactor-productivity have been used inefficiently. The results on structural changes that occurred in the economy reveal that as the manufacturing sector experienced an extensive fall it also had an impact on other sectors.

However, whereas in the second period most of high-tech manufacturing industries have had a negative contribution to aggregate value added, the KIS industries maintained slightly positive effects. This result could imply that there is no strict causality between the high-tech manufacturing and KIS industries. That is, the KIS industries are independent agents and are not fully dictated by fluctuations and changes in the manufacturing sector. Yet, the domestic demand of KIS industries might not be influential enough to cause a boost in the domestic manufacturing sector. The import of high-technologies and related equipment is still highly important for the Finnish economy.

In this thesis the interest has been on aggregate clusters of industries. As many features of the modern world are based on high class technologies, it was reasonable to focus on high-tech industries. By definition by Eurostat, the high-tech (HT class in earlier tables) manufacturing sector consists mainly of two industries. The class knowledge-intensive services cluster contains by far more industries. Therefore, the developing of each industry included in the KIS cluster could be quite different from one another.

There are some industries that are not of first importance to the development of value added and labour productivity (such as industries belonging to “Arts, entertainment and recreation“). On the other hand, the KIS cluster contains industries, which have a high demand for new technologies. They use and implement new innovations and might as well be initiatives for new technologies to emerge. In the past decade, the importance of these industries has been rising. They have become an important part in inspiring economic growth and improvements in labour productivity. For example, industries such as “Telecommunications” and “Computer programming, consultancy and related activities” have constantly increased their shares of value production and have been influential on labour productivity. A detailed analysis must be performed to understand better the variety included to aggregate KIS cluster. It must be also remembered that there exist differentiating industry-classification possibilities, one possibility to divide industries to subgroups could, for example, be by extracting the “high-tech knowledge-intensive services”.

7. Conclusions

The slowdown of multifactor- and labour productivity has been of a great concern in many developed countries, such as OECD economies. The recent labour productivity slowdown and the highly uncertain outlook for MFP growth have fueled a lively debate amongst economists on causes of these events. As neoclassical theory implies, the long-termed economic growth is due to a positive development of labour productivity. Especially in the case of the Finnish economy, the multifactor-productivity has been a great motivator of labour productivity growth.

The purpose of this study was to investigate the reasons behind the slowdown of economic growth of the Finnish economy and the stagnation of labour productivity. The study was executed with respect to capital services. The great contribution of this study to productivity analysis of the Finnish economy was the disaggregation of capital input into contributions of several capital groups. In this way, the magnitude of contributions of each capital asset type was inspected. The total capital input was divided into the subgroups of information and communication technology related assets, research and development capital, machinery and equipment capital and the group of non-residential buildings and other structures. Due to careful weighting scheme, each group of assets received an according weight to reflect the heterogeneous productive abilities of each capital type.

The methodology used in this thesis follows the methods developed by D. Jorgenson and is consistent with approaches of OECD productivity studies and the EUKLEMS-project. The method is based on the growth accounting framework and most of the data for this study were gathered from Finnish National Accounts and the Employment Statistics. The growth accounting methodology implies that the change in growth of output is investigated with respect to input factors–capital, labour and MFP. The measure of output in this study is measured in terms of value added.

At the industry level, the labour productivity measurement is defined as the annual change in total value added divided by the change in the total amount of hours worked. An additional component is added to the measurement of labour productivity at the aggregate economy level. The labour productivity at the whole economy level consists of aggregated labor productivities from industry level calculations plus the labour reallocation term, which implies, how effectively the worked hours have been allocated within industries with various value production capacities.

The main focus of this study was on aggregate level productivities. The full timeline of this study was 1995-2015. The time series was further divided into two periods, which were constructed in line with business cycles. The first period 1995-2005 captured the glorious time of the Finnish economy with the rise and strong effect of Nokia. The second period 2006-2015 described the dramatic decline in value producing capacities, drastic fall of multifactor-productivity and the stationary development of labour productivity.

The first part of the analysis focused on factors that were responsible for the negative performance of the Finnish economy in terms of economic growth and labour productivity. The two time periods were compared and the results established the factors which at first created the economic growth and were responsible for the boost in labour productivity but in the second period were found to be the main reasons for the slowdown. The decline in contributions of all input factors was discovered in the second period. However, it was the steep decline in multifactor-productivity that was the prime reason for the decline in growth of value added during the latter period 2006-2015. Despite remaining positive, the total contribution of capital input to value added had weakened in the past 10 years. The disaggregation of capital revealed that the highest fall is seen in contribution of R&D capital. The contribution of ICT capital was not as strong as in the prior period but remained significantly positive.

The results at the whole economy level labour productivity revealed that the main factor behind the slowdown was the sharp decline in MFP. The low or negative contribution of MFP can indicate, for example, that some organizational change or structural improvement is in progress and the positive outcome from this is yet to be seen. However, in the case of Finland this is doubtfully the case, since depressed growth of MFP is seen since the year 2009. The prolonged poor development of MFP implies that resources are not used in the most efficient way possible and that the ideas of improving production process and the new technologies to increase the value of the production have not been implemented.

Other significant factor that affected the whole economy level labour productivity negatively was the labour reallocation term. This finding implicates that the hours worked have been allocated to industries which have lower value production. Despite the fact that the average annual contribution of R&D capital to labour productivity was positive, a closer analysis of disaggregated capital showed signs of concern over declining trend in this set of capital.

The second part of the empirical research focused on structural change of the Finnish economy. The objective was to find out which industries have been most important to economic growth and which industries have affected the development of labour productivity. Again, by comparing the two periods 1996-2005 and 2006-2015, the changes in roles that some industries played in value production and labour productivity development were detected; for example, one industry could be particularly important during one period, but might no longer be in such a big role in the other period.

The main findings of the second part of the analysis revealed that the radical changes in high-tech and medium high-tech manufacturing industries have been the cause of the slowdown. In the first period, the influence of high-tech industries on the growth of MFP, value added and labour productivity was highly significant, but in the latter period the development of these industries has been on a downslope. Although decreased contributions were seen also for knowledge-intensive services, the overall decline was on average less than for the manufacturing industries. For example, in case of value added, the KIS industries were the main reason, why the total average growth of value added in the period 2006-2015 remained positive.

In this study, the KIS industry cluster contained 18 industries. The individual development of each industry of this cluster is most likely highly heterogeneous. The results for KIS industries presented in this study are annual average values. Further detailed examination of this cluster is needed to achieve a comprehensive understanding of the development and contributions of individual industries included to this class.

This study supports the view that the main sets of capital affecting the economic performance and labour productivity are ICT and R&D capital sets. The contribution of ICT capital to value added has decreased, but has remained positive. However, the movement of nowadays world towards digitalization might lead to situation where pure investments in ICT capital are no longer sufficient enough. Thus, some assets inside the whole ICT capital cluster might be more important for the economic development that others.

The results indicate that there is no need for general subsidies for example for investments in machinery and equipment. The evaporating contribution of R&D capital is, however, highly concerning. This study implies that the innovative and research activity of the economy has declined significantly. This is a matter of concern, because creating new technologies improves the competitiveness of domestic production and contributes to increasing value of the production. The stagnation of research and development activity and the negative growth of MFP might have far-reaching negative consequences on economic growth, labour productivity and competitiveness of Finland, if growth supportive measured are not undertaken.

The objectives of this study were achieved. The total capital input was successfully disaggregated and important information on how each set of capital has affected the performance of the Finnish economy has been gained. The results on structural changes in the Finnish economy revealed interesting, yet somewhat intuitive, evidence regarding the state of the economy. It must be remembered that this study took a specific point of view following designated methodology. There are many intriguing questions yet to be studied in the field of productivity research. These questions could specify the results of this study. Furthermore, it would be interesting to investigate the performance of some industries in more detail; for example, the individual industries included in the

KIS cluster. As well, excluding the effect of Nokia from the time series could also be an intriguing matter for further studies. Imitating international trends and investigating the endogenous nature of MFP would also be an important issue to study in the future.

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Annex

The measure of intermediate input includes either the imported intermediate inputs or purchased from the domestic markets. Through evolvement of productivity studies the method based on value added production function has entrench. Because of macroeconomic nature of growth accounting models, which are based on data from NA and such supranational projects as the EUKLEMS, the exact data on e.g. intermediate inputs could not be gathered properly. This might be one of the explanations, why the value added model has taken the lead.

The main difference between the gross output based and value added based models is that the former takes into account the contribution of intermediate input but due to its definition the value added function excludes the intermediate inputs. However, these differences exist only on industry level analysis. When the inspection is done on aggregate level of whole economy the relevance of intermediate input fades away, since it is rational to assume that industries undergo trade with each other in terms of intermediate inputs (i.e. some industries sell the other industries primarily only the intermediate inputs) but at the whole economy level this sense is lost. There are some measurement differences between this two methods, as well as there are differences in aggregating the factors from industry to whole economy level.

If the comparison would be made for a set of countries the relevance of intermediate input would be actual again, if it can be assumed that economies trade intermediate inputs with other economies. In this case, the value added method would not catch the additional effect of intermediate input, since the effect of producing the intermediate inputs would not be detected in value added of the entity producing the intermediate inputs. The effect of intermediate input would show in the value added of the economy, which purchased the intermediate inputs for its production.

Jorgenson *et al.* (2005) provide a more detailed discussion on the methods and the differences between them. When inspecting the productivity development at the whole economy level of one economy both methods should provide eventually the same results despite of the different methods used to aggregate the industry level data. The advantage of value added function arises in the aggregation and the analysis at the level of whole economy.

Annex. Table 1.

The data for the full inspection period of 1996-2015. The factor contributions to the value added growth of the Finnish non-residential market sector.

	Contributions of componens of value added equation									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Value added	**Total capital input**	**ICT**	**R&D**	**Machinery and equipment**	**Non-res.build.and other structures**	**Total labour input**	**LC**	**Hours worked**	**MFP**
1995	5.10	0.02	0.56	0.17	-0.48	-0.22	2.56	0.33	2.22	2.52
1996	4.60	0.19	0.19	0.27	-0.14	-0.13	2.02	0.42	1.60	2.39
1997	7.30	0.48	0.23	0.46	0.01	-0.22	2.83	0.08	2.74	4.00
1998	7.50	1.43	0.53	0.66	0.17	0.07	1.71	-0.24	1.95	4.35
1999	5.85	1.63	0.54	0.94	0.11	0.05	1.79	0.07	1.72	2.43
2000	7.26	1.82	0.56	1.00	0.16	0.09	1.56	0.02	1.54	3.88
2001	3.65	1.54	0.39	0.71	0.39	0.04	0.63	0.21	0.42	1.47
2002	1.47	0.70	0.18	0.37	0.10	0.04	0.32	0.29	0.02	0.45
2003	1.59	0.77	0.45	0.45	-0.11	-0.02	-0.26	0.20	-0.46	1.08
2004	5.36	0.59	0.31	0.44	-0.10	-0.05	0.54	0.14	0.39	4.23
2005	3.02	0.69	0.39	0.31	0.03	-0.04	0.98	0.21	0.77	1.35
2006	5.16	0.53	0.34	0.23	-0.02	-0.03	1.52	0.14	1.38	3.10
2007	7.75	1.15	0.50	0.37	0.20	0.07	1.74	-0.03	1.78	4.85
2008	0.43	1.18	0.37	0.51	0.20	0.10	1.59	0.19	1.40	-2.34
2009	-13.52	0.31	0.15	0.11	-0.01	0.07	-3.90	0.59	-4.49	-9.93
2010	4.86	0.00	0.09	0.08	-0.18	0.02	-0.28	0.01	-0.28	5.13
2011	2.08	0.00	0.12	-0.02	-0.12	0.01	0.86	-0.02	0.88	1.22
2012	-2.79	0.22	0.13	0.03	0.05	0.02	-0.06	0.01	-0.07	-2.95
2013	-1.98	-0.09	0.09	-0.03	-0.12	0.00	-1.20	0.35	-1.55	-0.69
2014	-0.62	0.04	0.15	-0.11	-0.09	0.08	-0.64	0.02	-0.66	-0.02
2015	-0.01	0.10	0.13	-0.10	0.03	0.04	-0.08	0.01	-0.10	-0.03

Note: (1) = (2) + (7) + (10) <=> (1) = (3) + (4) + (5) + (6) + (8) + (9) + (10)

Values in table are logarithmic percentage points.

Annex. Table 2.

The data for the full inspection period of 1996-2015. The factor contributions to the aggregate labour productivity of the Finnish non-residential market sector.

	Contributions of componens of labour productivity equation									
	(1) LP (whole economy)	(2) Total capital intensity	(3) ICT	(4) R&D	(5) Machinery and equip.	(6) Non-res.build. and other struc.	(7) LC	(8) MFP	(9) LP (aggregated)	(10) Labour reallocation term
1995	.	-1.04	0.50	-0.26	-0.92	-0.33	0.33	2.52	1.81	.
1996	2.00	-0.16	0.20	0.12	-0.26	-0.21	0.42	2.39	2.64	-0.64
1997	3.14	-0.44	0.18	0.26	-0.38	-0.48	0.08	4.00	3.64	-0.50
1998	4.44	0.29	0.44	0.22	-0.22	-0.15	-0.24	4.35	4.40	0.04
1999	3.03	0.95	0.54	0.50	-0.02	-0.04	0.07	2.43	3.44	-0.41
2000	5.16	1.13	0.44	0.77	-0.01	0.00	0.02	3.88	5.03	0.13
2001	3.15	1.42	0.38	0.70	0.39	-0.05	0.21	1.47	3.10	0.05
2002	1.14	1.42	0.23	0.69	0.32	0.18	0.29	0.45	2.17	-1.03
2003	2.17	1.42	0.48	0.56	0.17	0.20	0.20	1.08	2.70	-0.52
2004	4.63	0.58	0.32	0.42	-0.08	-0.08	0.14	4.23	4.96	-0.32
2005	1.65	0.75	0.39	0.12	0.22	0.02	0.21	1.35	2.31	-0.66
2006	3.05	0.16	0.26	0.29	-0.24	-0.14	0.14	3.10	3.40	-0.35
2007	4.78	0.84	0.45	0.30	0.10	-0.02	-0.03	4.85	5.66	-0.87
2008	-1.88	1.16	0.34	0.69	0.13	0.01	0.19	-2.34	-0.99	-0.88
2009	-7.58	2.73	0.43	0.98	0.74	0.60	0.59	-9.93	-6.61	-0.97
2010	5.29	0.36	0.14	0.34	-0.14	0.03	0.01	5.13	5.50	-0.21
2011	0.85	-0.07	0.11	0.10	-0.18	-0.09	-0.02	1.22	1.14	-0.29
2012	-2.99	0.26	0.15	0.02	0.12	-0.03	0.01	-2.95	-2.68	-0.30
2013	-0.18	0.50	0.16	0.14	0.03	0.10	0.35	-0.69	0.16	-0.35
2014	0.09	0.65	0.23	0.10	0.03	0.28	0.02	-0.02	0.65	-0.56
2015	0.08	0.55	0.17	0.07	0.11	0.19	0.01	-0.03	0.53	-0.45

Note: (1) = (9) + (10)

(9) = (2) + (7) + (8)

<=> (1) = (3) + (4) + (5) + (6) + (7) + (8) + (10)

Values in table are logarithmic percentage points.